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An analysis of Lemmings: a swarming approach to mine countermeasures in the VSW/SZ/BZ

Weber, Timothy R.

Monterey, California. Naval Postgraduate School

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THESIS

**AN ANALYSIS OF LEMMINGS:
A SWARMING APPROACH TO MINE
COUNTERMEASURES IN THE VSW/SZ/BZ**

by

Timothy R. Weber

December, 1995

Thesis Advisors: Carlos Borges
Bard K. Mansager

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Utilizing the Janus interactive wargaming simulation, an amphibious operation was modeled, with the amphibious landing taking place through a minefield in the littoral zones. Three scenarios of this model were developed: an amphibious landing through a minefield utilizing no clearing/breaching assets; an amphibious landing through a minefield utilizing current clearing/breaching assets; and an amphibious landing through a minefield utilizing Lemming swarms as the clearing/breaching assets.

A comparative analysis of these three scenarios will be performed, examining the measures of effectiveness of landing vehicles killed/damaged, combat power ashore at a given time, MCM assets killed, and percentage of mines neutralized.

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A SWARMING APPROACH TO MINE
COUNTERMEASURES IN THE VSW/SZ/BZ**

Timothy R. Weber
Lieutenant, United States Navy
B.S., Vanderbilt University, 1990

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Author: [redacted]
Timothy R. Weber

Approved by: [redacted]
Carlos Borges, Thesis Co-Advisor

[redacted]
Bard K. Mansager, Thesis Co-Advisor

[redacted]
Richard Franke, Chairman
Department of Mathematics

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Lemmings are autonomous tracked underwater vehicles which utilize a swarming approach to mine detection and neutralization in the very shallow water, surf, and beach zones (VSW/SZ/BZ). The Navy and the Marine Corps are in great need of developing an effective "in stride" clearance/breaching method to further enhance the effectiveness and viability of their littoral warfare skills. The Lemmings system has the potential to fulfill this critical need in a cost effective, reliable manner.

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I. INTRODUCTION

A. RESEARCH OBJECTIVE

The purpose of this thesis is to evaluate the tactical effectiveness of the Lemming swarming approach as a mine countermeasure in the very shallow water, surf zone, and beach zone (VSW/SZ/BZ) and compare this new technology with current naval mine countermeasure capabilities for conducting "in stride" breaching of a minefield in the VSW/SZ/BZ regions.

B. BACKGROUND

1. History

Mine warfare is by definition the strategic and tactical use of sea mines and their countermeasures, including all offensive and defensive mining and protection against mines. However, mining and mine countermeasures (MCM) are two distinctly different operations, both of which have significant places in the history of naval warfare.

The history of mine warfare in the United States dates back to the American Revolution and David Bushnell's famed experiments with underwater explosives and submersibles. In the summer of 1777, Bushnell cabled together a double line of contact mines (contact-primed powder kegs) to attack the British frigate Cerverus off the coast of Connecticut. The Cerverus survived, but only after a schooner was destroyed along with its crew while attempting to haul in the mines. Bushnell's early attempts at mining met with little success, though the attempt in this case turned out to be what was significant, not the failure of the mines to inflict relevant damage. [Ref. 1]

Bushnell's mine warfare efforts were in the mining arena, not mine countermeasures. Though mining plays a significant role in the history of mine warfare in the United States, so too do mine countermeasures. Mine warfare history is filled with accounts of naval efforts to counter enemy mines at sea. The first mine countermeasure device, a raft with grappling hooks, was used during the American Civil War by Union

forces in 1862. [Ref. 2] The advent and use of such MCM contributed directly to the success of America's most famous MCM operation, Rear Admiral David Glasgow Farragut's dramatic entrance through the mine line into Mobile Bay in 1864. The legend of Farragut's "damn the torpedoes" episode draws a picture of a daring man who risked an unknown mine threat to defeat the enemy. The reality is that Farragut was a daring man, but one who utilized every conceivable intelligence gathering capability available at the time to form an educated assessment of the mine threat before going "full speed ahead." As Tamara Moser Melia asserts in her book, Damn the Torpedoes: A Short History of U.S. Naval Mine Countermeasures, 1777-1991, the lesson we should have learned from Admiral Farragut's daring is not that you should boldly and blindly go forward into an unknown threat, but rather should meticulously examine, evaluate, and attempt to neutralize the threat prior to putting people and forces at risk. Admiral Farragut did not, as many assert, merely "damn" the mines at Mobile Bay but, rather, assiduously hunted, examined, and disabled them before steaming into the bay. [Ref. 1]

WWI was the first major war where the effects of mining had tremendous consequences on naval forces. The British were very successful in mining a significant portion of the North Sea in their efforts to keep the German fleet isolated. One of the most telling mining operations during WWI was conducted by the Turks in their efforts to defend the Dardanelles and Constantinople from Allied attack. In March of 1915, a force of some eighteen French and British battleships entered the Dardanelles in an effort to knock out Turkish batteries along the coast, breach known minefields, conduct naval bombardment of Constantinople, and hence split the Ottoman Empire. However, the operation did not go as planned. The Allies' inability to clear mines while faced with a battery of Turkish guns and the Turkish ability to lay mines relatively undetected during such an operation resulted in the sinking of three Allied battleships and severe damage to three others. In less than six hours, one-third of the Allied forces in the operation had been either damaged or destroyed. Not only did mines stop the Allied attack, but it also

forced the Allies into an amphibious raid of Gallipoli a month later. The amphibious operation resulted in 50,000 Allied battle deaths. Mining during WWI was so successful, in part, because this was the first major war where mining was used extensively and the shock value thus was great, and because mining technology was far ahead of mine countermeasure technology. WWI proved that mining was here to stay.

Of course, there are many other famous accounts of mining and MCM in the history of warfare. The aerial mining of Haiphong Harbor in 1972 stopped all ship movement and the U.S. had to conduct sweeping efforts as a condition of peace. In 1982, Argentina used obsolete WWI-era mines to block access to Port Stanley during the Falklands War. In 1984, Libya planted Soviet "export" mines in the Gulf of Suez and the Red Sea. Again, the U.S. was called upon to clean up the mines. We must not forget the Persian Gulf threat, where the USS Samuel B. Roberts struck a mine in 1988 and then during Desert Storm the *Tripoli* (LPH-10), the flagship of allied MCM operations, and the guided-missile cruiser *Princeton* (CG-59), each struck mines within hours of each other. Additionally, during Desert Storm, the U.S. would have had to face a very real mine threat had an amphibious landing eventually been ordered. In fact, the U.S. had been conducting extensive minesweeping operations in preparation for such an assault. Fortunately an amphibious assault was not necessary. [Ref. 1]

2. Amphibious Operations

a. Composition and Objective

An amphibious operation will be defined as an operation launched from the sea by naval and landing forces against a hostile or potentially hostile shore. There are four types of amphibious operations: amphibious assault, hostile or potentially hostile shore; amphibious raid; amphibious demonstration; and amphibious withdrawal. Each type of operation is designed to achieve specific and different results. This thesis will focus on the amphibious assault. The amphibious assault differs from the other operations in that it involves establishing a force on a hostile shore. Once ashore, the goal of such a

force is generally to: prosecute further combat operations; obtain a site for an advanced naval or air base; or deny the use of an area or facilities to the enemy. Given such critical goals, the amphibious operation is a complete operation within itself. It includes planning, embarkation of troops and equipment, rehearsals, movement to the objective area, final preparation of the objective, assault landing of troops and accompanying supplies and equipment, and continued support of the landing force (LF) until termination of the operation. Clearly, the success of such a complex operation requires intense coordination, clear communications, and thorough preparation and intelligence, among other things. Essential factors in the conduct of such an assault are flexibility of plans and speed in their execution. [Ref. 15] This thesis will analyze a potential asset in the form of the Lemming system for helping to ensure speed of execution in an amphibious landing.

The organization responsible for the amphibious assault is the amphibious task force (ATF). The assault phase of an amphibious operation begins when the assault elements of the ATF arrive in assigned positions in the objective area and terminates with the accomplishment of the ATF mission. The ATF always includes Navy forces and a LF, with aviation assets as required. The assault phase encompasses: preparation by air strikes and naval gunfire; ship-to-shore movement of the LF; landings in landing and drop zones and on beaches by the assault elements of the LF; operations inland to assist in seizing the beachhead; provision of logistic, air, and naval gunfire support of the attack throughout the assault; and finally the landing of remaining force elements required to complete the ATF mission. [Ref. 15]

The Navy forces of the ATF are composed of various task groups as required by the objective. Examples of such task groups are: Transportation Groups, which include all shipping in which the LF is embarked; Control Group, designed to control ship-to-shore movement; and the Mine Warfare (MW) Group, which is comprised of MCM and/or minelaying assets. There are other groups, such as Tactical Air Control Groups, Fire Support Groups, Screening Group, and several more, but they are not

relevant to the simulations created for this thesis. [Ref. 15]

The LF is comprised of command headquarters and the combat, combat support, and combat service support units, aviation and ground, assigned thereto to conduct the amphibious assault. The amphibious assault takes place within the assault area, which includes the beach area, the boat lanes, the lines of departure, the landing ship areas, the transport areas, and the fire support areas in the immediate vicinity of the boat lanes. The battalion landing team (BLT) is the basic task organization of the LF for the movement from ship to shore. The assault is initiated by the Assault Echelon (AE), composed of assault troops, landing craft, amphibious vehicles, helicopters, equipment, and supplies. The AE is launched from the line of departure, a designated line off-shore, approximately parallel to the landing beach. The AEs transit to the beach is conducted through boat lanes extending seaward from the landing beach to the line of departure. Each wave of the BLT, the first of which is in the AE, proceeds to designated landing zones as part of the total assault force effort at rapidly establishing a beachhead, a necessary requirement to expedite the landing of remaining troops and equipment. Establishment of the beachhead is the first major accomplishment toward meeting the ATF mission and completing the assault. [Ref. 15]

b. Operational Maneuver from the Sea

The objective of maneuver warfare is to collapse the enemy's will to fight. It seeks to shatter the enemy's cohesion through a series of rapid, violent, and unexpected actions, creating a turbulent and rapidly deteriorating situation with which the enemy cannot cope. This is accomplished by using tempo, speed, and surprise to apply strength against selected critical vulnerabilities of the enemy. [Ref. 3] Operational maneuver from the sea (OMFTS) is a blending of maneuver warfare with amphibious operations. Using the sea, air, and land as one maneuver space, the aim of OMFTS is to project the Marine air-ground task force ashore seamlessly, striking decisively at the heart of the enemy's will to resist. [Ref. 3] OMFTS makes the presumption that ships at sea and Marines on land

form a single, cohesive force, with no dividing line, either in time, space, or operational concept. As such, OMFTS can take full advantage of the extraordinary mobility offered by naval forces without loss of momentum during the ship-to-shore transition. Ideally, OMFTS offers an incredible opportunity to exploit our forces to their fullest extent while inflicting maximum damage on an enemy in a very short time. However, in practice, an OMFTS is full of many variables, some of which are potential show stoppers if unidentified and/or not appropriately dealt with in a timely manner. One such variable is mine warfare and the ever present threat of enemy mines.

3. Mines, Minefields, and the Enemy Threat

Many different mine capabilities are necessary to be able to conduct effective mine warfare in various situations. Consequently, there are many mine types and classifications, each designed to meet certain mine warfare requirements. Mines may be classified in several ways, for example as offensive or defensive, bottom or moored, contact or influence, as well as by size, type of influence, intended target, and method of delivery. Additionally, mines can be deployed in a wide range of depths, henceforth defined as follows::

* Deep water: greater than 200 feet
* Shallow water (SW): from 200 to 40 feet
* Very shallow water (VSW): from 40 to 10 feet
* Surf zone (SZ): from 10 feet to the high water mark (HWM)
* Beach zone (BZ): from the HWM inland

The BZ is sometimes referred to as the craft landing zone (CLZ).

A minefield (MF) is any collection of mines intentionally laid in some designated pattern or grouping intended to thwart the forward progress of an adversary. Minefields, like mines, may be classified as offensive or defensive. An offensive MF might be laid covertly in a foreign harbor or shipping channel, while a defensive MF might be laid along a coast line in order to prevent an attacking force from launching an amphibious landing.

The composition of a MF might include one type of mine or a combination of several types, all designed to affect specific enemy forces in a particular manner.

C. MINE COUNTERMEASURES

1. Background

In the words of Admiral Frank B. Kelso, Chief of Naval Operations (CNO), October 1991:

> ...I believe there are some fundamentals about mine warfare that we should not forget. Once mines are laid, they are quite difficult to get rid of. That is not likely to change. It is probably going to get worse, because mines are going to become more sophisticated. [Ref. 4]

With the brief history of mine warfare presented, the impact of mining and MCM is clear. The threat is real and the potential blow of mining great. The U.S. has been battling mines since the Civil War and the affects of mining on naval operations has changed little since. Mines in the Persian Gulf during Desert Storm served as yet another reminder of the importance of MCM and continued research and development efforts in the MCM warfare area. The CNO heeded the lessons and recognized the successes of mining and MCM during Desert Shield/Desert Storm and, as such, directed a new mine warfare plan to be developed and acted upon. On January 29, 1992, the Office of the Chief of Naval Operations, Department of the Navy, published the Mine Warfare Plan: Meeting the Challenges of an Uncertain World. [Ref. 4]

The Mine Warfare Plan (MWP) provides the framework for serious discussion of the requirements for an effective mine warfare force. Included is an assessment of the Navy's mine and MCM forces and capabilities in early 1992 and an outline of the strengths and weaknesses of those forces. Most importantly, the MWP discusses the Navy's mine warfare plan and strategy for dealing with future threats and calls for a greater commitment to effective utilization of current mine warfare assets and emphasizes the need to identify and develop new mine warfare technologies to meet anticipated future threats. [Ref. 4]

The MWP lists priority issues to be dealt with, one of which is an acknowledgment of the problems in conducting efficient, effective and speedy ("in stride") MCM operations in the VSW/SZ/BZ environments. Coupled with these priority issues are certain "critical initiatives and programs that we seek to emphasize in the coming years," one of which is the need to address the VSW/SZ/BZ mine/obstacle countermeasures problems. The MWP takes into account the need to:

> *enhance our MCM capabilities* for regional contingencies and independent operations, providing the people, training, *systems*, and *forces* upon which we will rely in the future. Most fundamentally, the MWP reflects the enabling role mine warfare plays in our ability to control the seas and *project military power into distant theaters*, during peacetime and war. [Ref. 4]

Following the spirit of the MWP, this thesis serves to enhance our MCM capabilities for dealing with the problems posed by mines in the VSW/SZ/BZ regions by investigating a new system, a new MCM technology, which may prove effective and lifesaving in dealing with such a threat, thus contributing to our ability to effectively project military power into distant theaters.

2. Role in Amphibious Operations

a. Current MCM Capabilities in the VSW/SZ/BZ

Though there are numerous MCM technologies being developed to combat mines in the littorals, the Navy must utilize today's technologies for any amphibious operations being planned or conducted in the near future. Unfortunately, there are few MCM capabilities designed specifically for certain littorals, and this is especially true if "in stride" operations are required. The concept of "in stride" will be discussed and defined in the following section. The Navy and Marine Corps must utilize existing technologies to combat mines in these regions. This calls for some innovative ways to employ current MCM forces, often resulting in the need to use a certain MCM technology in ways that it was not originally designed to be used.

b. In Stride MCM Capabilities

A senior official attending a mine countermeasures meeting in the fall of 1992 expressed the opinion that, "the Navy cannot sweep in stride, so the Marines will have to think up some other way of getting ashore." [Ref. 5] Progress has been made since 1992, but nevertheless, this is a damning quote which deserves further explanation. What is meant by sweeping "in stride" and what are the implications of such a statement? For this thesis, "in stride" sweeping will be defined to be the ability to breach a lane(s) through a minefield in the VSW/SZ/BZ just ahead of the LF, without impeding the schedule of the amphibious assault and without slowing the speed of advance of the LF due to a mine threat.

"In stride" sweeping is a formidable task. How close is the Navy to achieving such a capability? It is estimated that today's MCM assets can clear mines in water depths as shallow as 10 to 15 feet. For shallower depths, however, there is currently no acceptably reliable procedure for breaching mines in the SZ/BZ. This means that during the critical phase of an amphibious landing, the transition from sea to land, there is no sure way to combat the mine threat for these zones utilizing in stride breaching, and thus preserve the advantages of speed and surprise. This poses a great threat to the Marines and LF. [Ref. 6]

Of today's MCM forces, the assets which come closest to being able to provide "in stride" breaching are the MH-53E Sea Dragon helicopter towing the Mk 105 or Mk 106 Airborne Minesweeping System, the SPU-1W Magnetic Orange Pipe (MOP), and the Marine Corps' Amphibious Assault Vehicle 7A1 (AAV) series outfitted with MCM equipment. The Mk 105 simulates the magnetic signatures of various ships and the Mk 106 simulates both magnetic and acoustic signatures, sweeping for magnetic and acoustic influence mines, and can be towed up to speeds of 25 knots with a magnetic sweep width of some 600 feet. The Mk 105 is rated to a minimum depth of 15 feet, however, when dealing with a real-world threat, the Mk 105 could be towed up to three

feet of water. The Mk 105/106 hydrofoil sled has significant "combat" experience and has proven to be a highly effective MCM asset, having been used during Operation End Sweep in 1973 to sweep Haiphong's main shipping channel, to sweep the Suez Canal a year later, and most recently used in the Persian Gulf during Desert Shield/Storm. [Ref. 7]

The MOP is a magnetized pipe 30 feet long filled with styrofoam for buoyancy that can be towed up to 15 knots three in tandem, thus offering a magnetic sweep width of some 90 feet. The MOP can be towed to much shallower depths than the Mk 105/106, but has a tendency to lose its magnetic charge and hence is not as reliable a breaching/clearing method. [Ref. 2]

The Mk 105/106 and the MOP only counter the magnetic or acoustic mine threat and rely on helicopters, which are considered to be highly vulnerable in the flight envelope over the VSW/SZ/BZ regions. For this reason, it becomes necessary to equip AAVs or other capable landing craft with MCM to address the non-magnetic/non-acoustic mine threats in the SZ/BZ regions. The AAV can be equipped with the Mine Clearance System Kit, a modular line charge system which can be bolted into the cargo compartment. This is a modified M125 mine clearance system which uses a Mk22 rocket motor fired from an elevated launcher rail. The line charge has a 550 meter range, can clear 7m to either side of the line, and has an 80% clearance probability.[Ref. 12]

These MCM assets come close to meeting the "in stride" requirement, but none were designed for such a mission and are not reliable in the SZ/BZ environments. Of particular concern is the vulnerability of today's landing forces in the SZ region. Of all the current "in stride" MCM assets, none can effectively deal with mines in the SZ from about the 10 foot to 5 foot depth curve. This critical area will be referred to as the "gap", and presently there are no MCM assets capable of dealing with it in a reliable manner.

The Navy is pursuing a number of SZ/BZ specific research and development (R&D) efforts to meet the "in stride" criteria and fill the "gap". One program, the precision emplacement of large explosive charges (PELEC), calls for the

delivery by B-52 of 10,000-pound precision-guided bombs designed to penetrate to a depth of 21 feet into the bottom sediment and detonate within 0.01 seconds of each other to create a line-charge analog. Several versions of the PELEC are being researched. [Ref. 5] Another R&D effort involves outfitting the LCAC with mine-breaching equipment. The so-called "MCAC" will fire M58 line charges or similar explosive systems into the SZ/BZ during breaching operations. [Ref. 6] Several other R&D efforts are underway, all designed to counter the SZ/BZ mine threats. Unfortunately, none of these assets are fleet ready and certainly none have been tested with real-world threats. "The mine problem in the VSW/SZ/BZ is a special problem, and it requires nothing less than a special countermeasure." [Ref. 5]

c. MCM Problem Areas

The MCM problems associated with the VSW/SZ/BZ must be considered as major problems for the Navy, not just the MW community. In today's world, our forces will be and are called upon to deal with various regional threats, each with unique obstacles to overcome. Since the collapse of the Soviet Union, U.S. forces have been directly involved in at least five significant Lesser Regional Contingencies (LRC) or situations (Persian Gulf War, Somalia, Haiti, Rwanda, and now the Balkan crisis). Each of these LRCs either did involve or could have involved a naval mine threat, Rwanda excluded. Access to mines by Third World states is increasingly less difficult due to the huge inventory of Soviet mines in the newly independent former Soviet Republics and Russia. These states are in great need of cash and are quite willing to sell off their inventory of mines and other conventional weapons in order to generate such currency.

Mine warfare by its very nature is a significant threat. This threat is further complicated in the VSW/SZ/BZ. The waves, the general environment, and the density of mines in these zones make MCM that much harder. Add to this the requirement of "in stride" breaching and the difficulties of MW facing the Navy become clear. The SZ extends up to 350 yards from the beach along 75 percent of the world's coast lines. This

dynamic littoral zone, complicated by varying bottom types and tidal patterns, can be utilized by the enemy to create an extremely hostile barrier to a LF. Many different mine types, such as bottom contact, influence, moored, and anti-tank and anti-personnel mines, are available to potential enemies and are easily laid by a variety of means. Most mines can even be laid by hand in the SZ at low tide, thus accounting for the great mine densities in these zones. Also, the ease of covert mining has changed little since the Turks laid mines right under the noses of the British during the Dardanelle campaign in WWI. The "foam zone", the name given to the surf zone by Marine combat engineers, will continue to pose serious problems to MCM efforts and future amphibious operations until more reliable solutions are adopted or developed by the Navy. [Ref. 5]

3. Solutions to MCM Problem Areas

All of the R&D efforts toward MCM in the VSW/SZ/BZ offer a potential breakthrough in "in stride" capabilities, but are they cost effective and the best we can do? Only continued testing and development will answer such a question. But, there are alternative solutions being developed which might more effectively and economically solve our MCM problems. One proposed solution is the Lemming swarming vehicle.

a. Lemmings

Lemmings, developed by Foster-Miller, Inc. and currently undergoing field testing and analysis, were designed specifically to counter mines in the VSW/SZ/BZ utilizing a swarming approach to mine countermeasures. This thesis defines a swarm to be a large group of Lemmings employed together to sweep for and neutralize mines. Lemmings are small (about 0.8 cu/ft per vehicle), tracked, bottom crawling, expendable mine hunter-killers which counter mines in the VSW/SZ/BZ by employing a quasi-random search pattern which provides a high probability of successful neutralization of mines in specified landing zones. They are adaptable to various delivery means (air, surface, subsurface) and carry a wide variety of payloads, ranging from ordnance to surveillance. The cost per unit is very low and their advantages over traditional

clearance/breaching methods are numerous, including covertness, limited risk to personnel, reliability, robustness, and "in stride" breaching capability both in the water and on the beach. A Lemming vehicle is pictured in Figure 1. Details of Lemming specifications, operating parameters, and swarm characteristics are contained in Appendix A. [Ref. 8]

Figure 1. A Lemming Vehicle Detecting a Tilt-Rod Mine. Phote courtesy of Foster-Miller, Inc.

D. JANUS INTERACTIVE WARGAMING SIMULATION

1. Simulation Modeling

Computer simulation is a technique for using computers to imitate the operations of various kinds of real-world facilities or processes, called systems. An example of a real-world process (system) that is amenable to simulation is the effects of various traffic light timing schemes on rush hour traffic. In order to study such systems scientifically, a set of assumptions about how it works must be made. These assumptions, which usually take the form of mathematical or logical relationships, constitute a model that is used to try to gain some understanding of how the corresponding system behaves.

Most real-world systems are too complex to allow realistic models to be evaluated analytically, and these models are the ones that must be studied utilizing the advantages of simulation. In a simulation, a computer is used to evaluate a model numerically and produce data (output) in order to estimate the desired true characteristics of the model. Janus is a dynamic wargaming simulation used to imitate battlefield operations. [Ref. 9]

2. Combat Simulation with Janus

a. Characteristics of Janus

Janus is an interactive wargaming simulation initially developed by the Lawrence Livermore National Laboratory. The Army has updated and revised the program over the years to meet both combat development and training needs. The model is written in FORTRAN and has been adapted for use with the UNIX operating system in a desktop computer network. Janus(A), version 3.15, was used for this thesis.

Janus is a high resolution, interactive, two-sided, closed, stochastic, ground combat simulation. This high resolution model allows the user to create units as small as individual infantry and vehicular weapons systems and place these systems in ground combat scenarios where the focus of the simulation is on the maneuver of the systems either individually or as elements of larger units. The scenarios developed are two-sided, placing two forces, Blue and Red, in opposition to each other. The simulation is closed so that the disposition of one opposing force is unknown to the other until force locations are disclosed through direct observation and contact or through intelligence reports generated by friendly forces. It is interactive because it allows the user to make changes in the scenario as events unfold without stopping the simulation. Finally, stochastic refers to the way the system determines the results of actions like direct fire engagements or minefield crossing events: according to the laws of probability and chance. [Ref. 10]

b. Major Features and Capabilities

The user runs simulations on digitized terrain maps developed for Janus from Defense Mapping Agency data. Each terrain map is a computer reproduction of

actual terrain and is displayed in military format using the Universal Transverse Mercator grid system. These terrain maps realistically model terrain contour, roads, vegetation, water and other obstacles. Janus also simulates the effects of light and weather. These factors all affect system movement, visibility, and target acquisition and must be considered when planning a scenario. [Ref. 10]

The user plans the scenario and controls the battle with a mouse. The user may task organize units and place them in defensive positions or put them in an offensive posture. Units may be in full defilade, partial defilade, or put in prepared fighting positions. The user may designate movement routes from one position to another and plan movement starts and stops at specific times in the scenario. These routes and times may be altered at any time in the scenario before execution. Units on the move are in an exposed status but automatically go into partial defilade after stopping. Any weapons systems, whether on the move or stationary, may be placed in holdfire status. This capability allows the user to plan and direct fire on command. [Ref. 10]

The user may designate some vehicles as troop carriers and mount or dismount them on command. The user may create minefields and simulate other man-made obstacles such as abatis, ditches and craters. Engineer vehicles may be equipped to breach and clear these minefields and obstacles. The user may also create artillery and mortar systems and plan indirect fire missions. Other systems may be designated as smoke generators that may be used to simulate the obscuration effects of smoke on the battlefield. [Ref. 10]

The capabilities and features mentioned are just a few of those available to the user. Janus has an extensive and detailed database which the user can use to model systems and scenarios. The Janus developmental database has three major sections: combat systems, terrain maps and symbols, and testing and analysis. The combat systems database is the portion in which the user creates new systems and alters existing ones. In the terrain and symbols database, the user can edit terrain maps, create and alter system

graphic symbols, and create map overlays for use in wargaming. For testing and analysis, the user puts systems and terrain into a scenario in which the systems and associated tactics can be tested. The user can then collect and analyze data through the post-processor to measure the effects of changes in systems and tactics.

3. Using Janus to Meet Research Objectives

This thesis utilizes Janus in evaluating the tactical effectiveness of the Lemming swarming approach to "in stride" MCM in the VSW/SZ/BZ. The tactical effectiveness of the Lemmings swarming concept was evaluated through a comparative analysis with traditional MCM (today's capabilities) and a bull breaching (no mine clearing) approach to MCM. The bull breaching method served as a base line data generator with which to compare the other methods.

a. Advantages of Using Janus

In order to meet the research objective, three scenarios were developed in Janus, each identically modeled except for differences in MCM method employed. Janus offers an advantage of being able to create (simulate) identical environments in multiple scenarios through which comparative analysis can be performed. The environments created can be altered between scenarios as much or as little as desired in order to measure the effects of such changes on the model. The real utility of simulation lies in the ability to analyze and make predictions about new systems and tactics through the comparison of such alternative scenarios prior to actually developing or testing real-world systems and tactics. Indications about a system's potential can be realized through simulation modeling, and as such, help shape the path that R&D of that system takes.

(1) Functional vs. Operational Aspects. Janus offers the advantage of being able to both evaluate a system's operational aspects (characteristics and performance capabilities) and a system's functional aspects (specifications). The operational aspects of Janus are realized during scenario execution and post-processing data analysis, while functional aspects are realized through data base user *inputs*. A

system's functional aspects directly affect that system's operational aspects. For instance, the modeling of a system, such as a Landing Craft Air Cushioned (LCAC), takes place in the data base (functional), while its performance and effect on various aspects of a scenario (operational) are evaluated during scenario execution and post-processing.

b. Scenarios of Interest

The scenarios developed to meet the research objective are:

* Bull Breaching: an amphibious landing through a minefield in the VSW/SZ/BZ with no breaching operations.

* Traditional: an amphibious landing through a minefield in the VSW/SZ/BZ with current (today's technology) MCM assets being used for breaching.

* Lemmings: an amphibious landing through a minefield in the VSW/SZ/BZ utilizing Lemming swarms as the breaching method.

In developing these scenarios, crucial assumptions were made concerning several aspects of the assault. These assumptions will be discussed in Chapter II.

II. MODEL DEVELOPMENT

A. JANUS COMBAT SYSTEMS DATA BASE

It is within the Combat Systems Data Base (CS) that each individual system (e.g., LCAC, AAV, MH-53E, etc.) is created, edited, and maintained. Data base inputs include such system characteristics as dimensions, weight, carrying capacity, and speed. Additionally, weapon and sensor types and capabilities could have been incorporated into the data base.

Mine types and minefield classifications are also defined by the user within the CS Data Base, as are each system's vulnerabilities to each mine type. The assignment of a breaching capability to an individual system is made within the Force Definition file of Janus. However, the effectiveness of each breaching method (e.g., plow, roller, line charge) is assigned within the CS Data Base. In addition to breaching method effectiveness, each method is also assigned a survival probability specifying the likelihood that an MCM system will survive given that it has encountered a mine. For example, a mine breaching plow attached to a tank may be assigned an 80 percent chance of successfully neutralizing a certain mine type (method effectiveness), but only a 75 percent chance of surviving given that it encountered that same mine (method survivability).

Each system which is created within the CS Data Base is also assigned certain probabilities relating to mine encounters. For instance, an LCAC might be assigned an 85 percent chance of activating a magnetic mine and, if mine activation occurs, only a 40 percent chance of actually being killed by that mine. Each system is assigned different mine activation and mine kill probabilities for each type of mine being modeled within a given scenario (e.g., magnetic, anti-tank, bottom contact, etc.). System vulnerability probabilities to mines and breaching method effectiveness probabilities specific to this thesis are outlined in Appendix B.

B. ASSUMPTIONS AND SYSTEM DEVELOPMENT

1. Amphibious Landing

This thesis makes the assumption that the LF will be launched from the ATF over-the-horizon (OTH) at approximately 20 nm off shore from the amphibious objective area (AOA). The objective of this landing is assumed to be the establishment of a beachhead.

2. Landing Area

The landing area (LA) is that part of the objective area within which landing operations are conducted. It includes the beach, the approaches to the beach, the transport areas, the fire support areas, the air occupied by close supporting aircraft, and the land included in the advance inland to the initial objective. This thesis will refer to the LA as the landing zone (LZ) and limit this zone to include the VSW/SZ/BZ, the landing lanes, craft landing site, and the bottom contact point (BCP). The BCP refers to that point at which an amphibious landing vehicle first touches the bottom (about 5-7 foot depth for a AAV). A schematic of the LZ is shown in Figure 2.

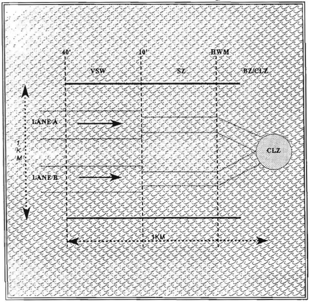

Figure 2. Schematic of Amphibious Landing Zone.

Landing lanes refer to both the boat lane and the actual landing lane. The boat lane has been modeled to be a 150 meter wide lane that extends through the VSW, up to, but not into, the SZ. The landing lane extends from the end of the boat lane, through the SZ/BZ, and terminates at the landing site, and has been modeled to be 50 meters wide. The LZ has been modeled to be contained within a 1 square kilometer region. [Ref. 13]

It must be understood that the attacking force selects the landing site, not the defending force. However, since only certain coastal areas are conducive to an amphibious landing, the defending force can make educated guesses about the location of a possible amphibious assault. Several factors contribute to the decision as to where to land the force. These factors include such considerations as access inland once ashore, landing site vulnerability to enemy fire, tidal conditions, weather patterns, coastal topography, and beach gradient. It is beach gradient which directly affects the work load on the MCM effort and the danger to the LF. Knowledge of the beach gradient is vitally important, because beach gradient is what determines the likelihood of enemy mines being present and provides the basis for estimates of mine densities in the VSW/SZ/BZ regions. For instance, a short, steep beach will not offer the defending force much room to lay mines, while a flat beach will allow for extensive mining. This thesis will assume a flat beach gradient, thereby affording the defending force the opportunity to lay a worst case density minefield. The tide is assumed to be low during the assault, thus further increasing LF exposure to mines on the beach. [Ref. 11]

3. Mine Warfare Group

This section looks at the "decisions" made by the fictitious Commander, MW Group (CMWG), for each scenario. These "decisions" are the author's assumptions concerning the MCM assets for each scenario. Each CMWG has been tasked with accomplishing "in stride" breaching for their respective scenario.

a. Bull Breaching

For the Bull Breaching Scenario, the CMWG has decided to accomplish his

"in stride" MCM objective by bull breaching the LF through the MF. The landing formation of the LF will be described in a later section.

b. Traditional

For the Traditional Scenario, the CMWG has decided to utilize the following MCM assets described in Chapter I, section C:

* MH-53E Sea Dragon helicopters towing the Mk 105 magnetic sweep hydrofoils.

* Amphibious Assault Vehicles equipped with a line charge system (AAVLC).

* Amphibious Assault Vehicles equipped with mine clearing plows (AAVP).

The assumption is made that a reliable MCM plow is in service, which one currently is not, although the Caterpillar Corporation has developed and is testing what might be an effective plowing system. Additionally, use of the MOP has been omitted based on the fact that its reliability is significantly lower than that of the Mk 105 that its use would only risk more helicopter assets than necessary to meet the "in stride" breaching objective. The AAV MCM assets are employed just prior to the BCP. The decision has been made that should breaching assets be destroyed, the LF will continue the assault.

The author realizes that in a real-world situation, more assets would likely be used to further breach and proof lanes. Furthermore, this thesis does not take into account the use of special forces conducting covert mine clearing/marking prior to an assault. However, the comparative and relative nature of this thesis, comparing one MCM asset against another, all else being equal, permits such asset omissions. In a real-world situation, Lemmings would likely be supplemented with other assets as well.

c. Lemmings

The Lemmings Scenario CMWG has decided to utilize Lemmings swarming vehicles as the only "in stride" breaching asset. Lemmings are assumed to be capable of command detonation or timed detonate in order to preserve their covert operation, although R&D of such a capability is still in its preliminary stages.

4. Landing Force

To land a typical Assault Echelon (AE), the Amphibious Task Force (ATF) has 30 Landing Craft Air Cushioned (LCAC) and 36 Amphibious Assault Vehicles (AAV). It is assumed that a force such as this will require 90 LCAC loads in order to deliver the required combat assets ashore. This assumption is based on the lift capacity of the LCAC and the force requirements needed ashore for a typical offensive amphibious operation, such as the one which was planned but never carried out during Desert Storm. This thesis will further break down the AE and will focus on a single Battalion Landing Team (BLT), using 10 LCACs and 13 AAVs to move the BLT ashore. The number of LCAC loads for one BLT is assumed to be 30 (one-third of the 90 needed by the entire AE). However, this thesis further refines the AE by analyzing the landing of the BLT's 13 AAVs and only one round-trip of the 10 LCACs attached to the BLT, instead of the three round-trips that would actually be required. By focusing on this abridged BLT for modeling purposes, total force effects are not lost. Simple extrapolation can be used to see the effects on an entire AE. [Ref. 11]

It is assumed that the AAV is capable of an OTH assault. The AAV7A1 moves only at 8 knots at sea, and the combat effectiveness of the troops within begins to decline after only 30 minutes due to noise, fumes, heat, and motion. These deficiencies allow for a line of departure of only 2 nm from the beach, which is clearly not OTH. This thesis assumes that the AAV can conduct effective OTH assaults. This assumption is based on the capabilities of future assault craft, such as the Advanced Amphibious Assault Vehicle.

The LF will make its approach in echelon and wedge formations, moving into columns just prior to entering the landing lanes. The AAVs will cross through the lanes ahead of the LCACs, moving through the littoral zones utilizing both lanes, and once ashore advance inland to clear the landing site for the LCACs. The LCACs will make their beach approach through lane A, offload their equipment at the landing site, and then depart for their return to the ATF through lane B.

5. Minefields, Mines, and Minefield Densities

a. Minefields and Employment Methods

Janus models five kinds of minefields: hand emplaced, ground vehicle emplaced, artillery emplaced, helicopter emplaced, and a manually operated portable minefield. Obviously, with Janus being designed to model ground combat, these "canned" minefields are specifically designed to simulate land minefields. As will become clear, it is possible to manipulate the databases of these five types of minefields so that one can transform one of these land minefields into an ocean/littoral minefield. The author utilizes the hand emplaced (HAND EMP), ground vehicle emplaced (MECH-1), and the helicopter emplaced (MECH-2) minefields. Due to the stochastic nature of Janus, each time a scenario is run, the placements of mines within the designated minefields are different from previous executions of the same scenario (i.e., mine location within minefields is random).

A single HAND EMP minefield consists of 99 mines placed regularly in a 50 by 100 meter rectangle. The mines within this minefield are located in three strips of 33 mines each. The three strips are 15 meters apart and within a single strip, the mines are placed every 3 meters, alternately 3 meters to one side or the other of the strip. It should be noted that each time a scenario containing HAND EMP minefields is run, the placement of the mines along each of the three strips is random, only the spacing between the mines is a constant 3 meters. HAND EMP minefields are located and oriented by the user during initial planning (prior to execution of the scenario). The number of desired HAND EMP minefields is generated by entering the desired number of HAND EMP into the Mine Type 1 field on Janus screen III.

MECH-1 emplaced minefields consist of mines that have a uniformly random distribution within each minefield. The length and width of MECH-1 minefields can be altered and set by the user. The user chooses either low (40 mines), medium (80 mines), or high (160 mines) density, positions, and then orients the minefields during

initial planning. This type of minefield may be deployed either during initial planning or during the scenario execution phase. The number of desired MECH-1 minefields is generated by entering the desired number of MECH-1 into the Mine Type 2 field on Janus screen III.

Janus only allows for HAND EMP and MECH-1 minefields to be positioned during the initial planning phase of a given scenario. The remaining three types of minefields must be interactively laid by the user during the scenario execution phase. As a result, the MECH-2 minefields being utilized in this thesis must be interactively laid once scenario execution has occurred.

The MECH-2 minefield is emplaced by giving a helicopter a movement route over the minefield site and dropping the MECH-2 minefields at the desired location. The orientation of the minefield is that of the helicopter's flight path. The user decides through mouse commands when to drop the minefields from the helicopter. The dimensions of the minefield can be altered by the user. The mines within MECH-2 minefields are randomly but uniformly distributed within the minefield dimensions. The densities are selected in an identical manner as that of the MECH-1.

b. Mine Types

This thesis assumes the following mine types have been laid in the specified zones:

* Magnetic influence mines in the VSW
* Bottom contact mines in the SZ (5 to 10 feet depth)
* Anti-tank mines in the SZ (5 feet depth to HWM) and BZ

Of the five types of minefields, each can contain only one type of mine. There are 10 types of mines available in Janus, each type being defined by designated probabilities. It should be pointed out that one Janus minefield is not equivalent to the author's one square kilometer enemy minefield, through which the AE will cross. The enemy minefield is composed of a number of Janus minefields selected so that the enemy

minefield densities and mine types are appropriate for each littoral zone.

This thesis utilizes three of the ten mine types available. As discussed earlier, one central aspect of the VSW/SZ/BZ mine threat is that adversaries intent upon denying U.S. and allied access to the beach will employ as many different types of mines as possible in the amphibious objective area (AOA), ranging from influence mines in the VSW/SZ, to anti-invasion and anti-tank mines in the SZ/BZ region. [Ref. 11] As previously mentioned, this thesis will assume magnetic influence mines in the VSW, bottom contact in the SZ, and anti-tank mines in the SZ/BZ region.

Janus mine type 1 will be designated as anti-tank mines and will be dispensed by the HAND EMP method in the SZ/BZ region. Janus mine type 2 will be designated as bottom contact mines and will be dispensed by the MECH-1 method in the SZ region. Finally, Janus mine type 3 will be designated as magnetic influence mines and will be dispensed by the MECH-2 method in the VSW region. Again, the mine types are defined by various probabilities which are appropriate for the mine type being modeled.

c. Densities

The minefield densities are assumed to be worst case:

* 500 mines per square kilometer in the VSW
* 1000 mines per square kilometer in the SZ
* 2000 mines per square kilometer in the BZ

The density assumption is directly linked to the flat beach gradient assumption and densities can be considered inversely proportional to depth. [Ref. 11] Expected mine densities in the landing lanes were calculated using the worst case densities above and landing lane area per littoral zone. The results of the calculations indicate that 80 mines per lane can be expected, on average, for each scenario run, or 160 mines between the two landing lanes. Figure 3 is a schematic of the minefield densities.

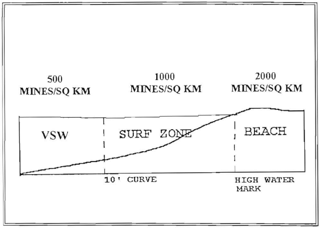

Figure 3. Beach Profile Showing Worst Case Mine Densities.

6. Enemy Forces and Naval Gunfire Support (NGFS)

It is assumed that the amphibious landing will take place unopposed by enemy forces. This assumption was made in order to establish a clear base case comparison between MCM assets. Additionally, the amphibious landing has not been modeled to be covered by NGFS or air support. However, Janus allows for such modeling and any future studies of MCM assets and amphibious operations could incorporate such additions.

C. SCENARIO DEVELOPMENT

1. Bull Breaching Scenario

The Bull Breaching Scenario simulates an amphibious landing through mined littoral zones without breaching operations being conducted prior to the assault. The intent of this scenario is to gauge the effect that heavily mined littoral zones would have on an amphibious assault being conducted with no breaching operations. The data generated from this scenario serves as a baseline for comparative analysis with the other scenarios of interest. The expectation is that the LF will experience significant losses on average during scenario execution. But, regardless of the results, the data generated will be used to gauge the relative effectiveness of both traditional and Lemming MCM

methods employed in the other scenarios. Despite not utilizing any sound breaching method, the LF will nevertheless transit the littoral zones in the column formations previously discussed.

2. Traditional Scenario

The Traditional Scenario is an exact copy of the Bull Breaching scenario, except that prior to the assault, MF breaching is conducted in the VSW/SZ/BZ regions, attempting to clear the two landing lanes. As previously mentioned, traditional MCM assets being utilized for "in stride" breaching include the following:

* Four MH-53E Sea Dragon helicopters towing Mk 105 magnetic minesweeping hydrofoils to counter the magnetic mine threat in the VSW.

* Two AAVLCs.

* Four AAVPs, intended to proof the lanes cleared by the line charges.

The sequence of this traditional "in stride" breaching operation is as follows: first, two Sea Dragons per lane sweep the VSW up to about the 8 to 10 foot depth, clearing the two 150 meter wide lanes in the VSW region; second, one AAVLC per lane fires its line charge at about the BCP (5 foot depth line), ideally breaching a 15 meter wide landing lane from the BCP to the landing site; and finally, two AAVPs per lane follow the AAVLC, commencing plowing operations at the BCP, and ideally proofing and widening to about 30 meters the landing lane up to the landing site. Once the lanes have been breached, or MCM assets killed, the remainder of the LF will proceed with the assault.

3. Lemming Scenario

As with the Traditional Scenario, the Lemmings Scenario is a copy of the Bull Breaching Scenario, except, of course, for the MCM method employed. This scenario utilizes one Lemmings swarm per lane, each swarm consisting of 130 Lemmings, to breach the two landing lanes. The size of each swarm was calculated using the estimated mine densities per lane and the 1.62 Lemming-to-mine ratio suggested by Foster-Miller.

The Lemming swarms are deployed by SEAL teams from 6 ZODIACs at the mouth of the landing lanes, at about the 40 foot depth curve. The deployment occurs just before dawn and about 90 minutes from H-hour, the time that the first vehicle reaches the landing site. This time frame enables the last of the BZ mines to be neutralized by Lemmings just as the first wave of the LF reaches the VSW.

4. Measures of Effectiveness (MOE)

a. MOE 1

MOE 1, combat power ashore, is a critical indicator of the relative success of the "in stride" MCM operations conducted prior to the assault. MOE 1 is relevant to single scenario analysis and comparative analysis of all three scenarios.

b. MOE 2

MOE 2, landing force kills experienced during the assault, is also a critical indicator of the relative success of the "in stride" MCM operations conducted in each scenario. The analysis of MOE 2 is also relevant to each scenario and to a comparison between scenarios.

c. MOE 3

MOE 3, total MCM assets killed, applies specifically to the Traditional Scenario, and as such, is of little value for comparative analysis between scenarios. However, MOE 3 offers significant insight into the analysis of MOE 1 and MOE 2 with respect to the Traditional Scenario.

d. MOE 4

MOE 4, number of mines neutralized versus expected number of mines per landing lane, is relevant only to the Lemmings Scenario. The analysis of MOE 4 contributes to the analysis of MOE 1 and MOE 2 with respect to the Lemmings Scenario. It should be noted that the number of mines neutralized (killed) in the Lemmings Scenario is equal to the number of Lemmings killed.

5. Scenario Execution

A collection of color slides taken during the running of each scenario are contained in Appendix C. A brief description of each image is presented and they are listed in chronological order.

6. Data Collection and Analysis Concept

As a stochastic simulation, Janus produces output that is itself random, and must therefore be treated as only an estimate of the true characteristics of the model. The stochastic nature of Janus output makes comparing the three scenarios on the basis of only a single run of each a very unreliable approach to analysis. Consequently, 10 runs of each scenario were conducted in order to increase the accuracy and significance of the comparative analysis conducted on the different MCM methods.

Data collection is accomplished using the Janus Post Processing (PP) program. The PP lets the user retrieve reports compiled from recording files made during a simulation run. There are ten PP reports available, ranging from an Artillery Impacts Report to Temperature and Workload Profiles Report. The analysis for this thesis utilizes the Coroner's Report (CR) and the Minefields Report (MR). For each run of each scenario, these two reports were generated using the Janus PP.

The CR provides a detailed account of each kill. Each row gives information about a single kill, and the rows are in chronological order. Information provided includes time of kill, kill type, name of unit killed, location of kill, and information on the killer.

The MR furnishes information about minefields and minefield encounters. The MR is divided into two sections, the first is the Minefield Summary Report (MSR) and the second is the Minefield Crossing Events Report (MCR). The MSR displays one row for each MF, providing information on the type of mine within the MF, the method for laying that MF, location and dimension of the MF, orientation angle, and density of the MF. The MCR displays the following information about units that encountered a given MF: time of encounter, name of unit crossing a MF, whether that unit is conducting breaching

operations or not, entrance and exit points, and the MF number.

Graphical and statistical methods of data analysis are used in this thesis. Graphical analysis includes multiple and single box plots of different kill categories, graphs of combat forces ashore versus time, a bar graph comparing percentage of breaching completed to percentage of landing forces killed, and finally data tables summarizing different MOE categories. Although histograms are often very useful tools for analyzing and summarizing data distributions, they offered no insight because of the relatively low number of scenario runs performed.

Box plots are summary displays of the distribution of data and provide an immediate look at the prominent features of distributions. They give indications of the spread, density, and skewness of data, and are especially useful in identifying the means and medians of distributions. A sample box plot is shown in Figure 4.

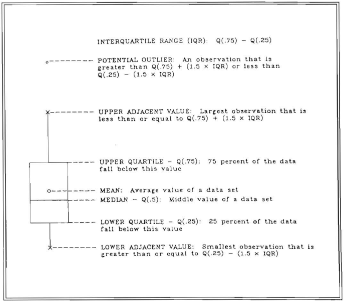

Figure 4. Sample Box Plot with Legend.

Multiple box plots are good tools for comparing distributions of different samples. The multiple box plots used in this thesis compare different landing force kill category totals between the three scenarios. They will indicate whether these distributions are similar and highlight the differences (or similarities) in distribution locations among the different MCM methods tested.

The Mann-Whitney U test, a nonparametric statistical procedure, was used to analyze the kill data, since the outcomes from this simulation have an unknown distribution. The Mann-Whitney U test requires the samples to be randomly and independently selected from their respective populations and the U statistic is obtained by ordering all $(n_1\ n_2)$ observations according to their magnitude and counting the number of observations in sample A that precede each observation in sample B. The U statistic is the sum of these counts. This test is used to decide whether differences among samples indicate that these samples are taken from different populations or whether they represent variations expected among random samples from the same population. It tests the null hypothesis,

H_o: The population relative frequency distributions for A and B are identical,

against the alternative hypothesis,

H_A: The population relative frequency distribution for A is shifted to the right of the relative frequency distribution for population B (one-tailed test).

For a more detailed description of the Mann-Whitney U test, refer to Reference 14.

III. ANALYSIS

A. SCENARIO ANALYSIS

Analysis of the post-processing data generated from runs of each scenario is conducted in this section. Comparative analysis between scenarios is conducted in the next section. General descriptive statistics (e.g., mean, median, variance) for each scenario are contained in Appendix E. Recall that data was generated from 10 runs of each scenario. The expected results of the analysis follow from experience and knowledge of MCM method capabilities: Bull Breaching is expected to be the least successful of the breaching methods; Traditional Breaching is expected to be significantly better than Bull Breaching; and Lemming swarms, according to system characteristics, operating parameters, and expectations, are expected to outperform traditional breaching. The following analysis will support or weaken such expectations.

1. Bull Breaching Scenario

a. MOE 1

Table 1 contains data on combat power ashore (CPA) extracted from the Coroner's Report. Combat power ashore figures were arrived at by using the number of kills per run obtained from the CR and extrapolating information from the known time of individual kills. For instance, an LCAC has two opportunities to be killed, inbound or outbound. If an LCAC was killed inbound, then that LCAC is excluded from CPA calculations. But, if an LCAC survives its inbound assault, only to be killed outbound, that LCAC was able to off load its contents at the landing site and thus is included in CPA calculations. In the case of the AAVs, AAVs do not return through the MF, so either they project CPA or they are killed.

Table 1 breaks down CPA by individual run as a function of five minute time intervals. The aggregate total CPA (average total over the 10 runs) for the Bull Breaching Scenario was 2.5 landing vehicles ashore.

COMBAT POWER ASHORE; BULL BREACHING SCENARIO												
RUN NUMBER	SCENARIO TIME (MINUTES) 110	115	120	125	130	135	140	145	150	155	160	TOTAL ASHORE
RUN 1	0	0	0	0	0	0	0	0	0	0	0	0
RUN 2	0	0	0	0	1	0	0	1	2	0	0	4
RUN 3	0	0	0	0	0	1	0	0	1	0	0	2
RUN 4	0	1	0	0	0	0	2	0	1	0	0	4
RUN 5	0	0	0	0	0	0	0	0	0	0	0	0
RUN 6	0	0	0	0	0	1	0	0	2	0	0	3
RUN 7	0	0	0	0	0	0	1	3	1	0	0	5
RUN 8	0	1	0	0	2	0	0	0	1	0	0	4
RUN 9	0	0	0	0	1	0	0	0	1	0	0	2
RUN 10	0	0	0	0	0	0	0	0	1	0	0	1
AVERAGE	0	0.2	0	0	0.4	0.2	0.3	0.4	1.0	0	0	2.5

Table 1. Combat Power Ashore as a Function of Time; Bull Breaching Scenario.

b. MOE 2

Table 2 contains information extracted from the CR and includes such landing force kill categories as total LF kills, total AAV kills, total LCAC kills, and inbound/outbound LCAC kills. Each kill category is further broken down by littoral zone kills. Data on each Bull Breaching Scenario run is included, as well as aggregate kill figures. Areas to focus on include the "gap" kills (i.e., SZ kills) and total kills per category. Obviously, aggregate total LCAC kills plus aggregate total AAV kills equals the aggregate total LF kills of 22.2 vehicles. Recall that the LF is composed of 23 vehicles, 10 LCACs and 13 AAVs. So, an aggregate total LF kill figure of 22.2 indicates that, on average, 97% of the LF was killed during each Bull Breaching assault. It is safe to say that such kills are devastating to any assault.

Also of interest is the high number of aggregate inbound LCAC kills. This clearly indicates the presence of a very dense minefield. It is expected that if MF breaching is reasonably effective, which bull breaching is obviously not, that about the same percentage of LCACs would survive inbound as outbound. This expectation will be analyzed in the Traditional and Lemmings Scenarios sections.

LANDING FORCE KILLS; BULL BREACHING SCENARIO					
RUN NUMBER	TOTAL KILLS VSW SZ BZ TOTAL	AAV KILLS VSW SZ BZ TOTAL	LCAC KILLS VSW SZ BZ TOTAL	LCAC KILLS INBOUND	LCAC KILLS OUTBOUND
RUN 1	6 7 10 23	3 4 6 13	3 3 4 10	10	0
RUN 2	2 6 14 22	2 4 6 12	0 2 8 10	7	3
RUN 3	5 12 5 22	5 7 0 12	0 5 5 10	9	1
RUN 4	5 9 8 22	4 7 1 12	1 2 7 10	7	3
RUN 5	8 7 8 23	5 5 3 13	3 2 5 10	10	0
RUN 6	3 10 9 22	3 8 1 12	0 2 8 10	8	2
RUN 7	5 4 14 23	4 3 6 13	1 1 8 10	5	5
RUN 8	3 5 12 20	2 4 4 10	1 1 8 10	9	1
RUN 9	3 7 12 22	0 6 6 12	3 1 6 10	9	1
RUN 10	5 6 12 23	5 4 4 13	0 2 8 10	9	1
AVERAGE	4.5 7.3 10.4 22.2	3.3 5.2 3.7 12.2	1.2 2.1 6.7 10	8.3	1.7

Table 2. Landing Force Kills; Bull Breaching Scenario.

Figure 5 is a box plot of total LF kills for Bull Breaching. The position of the median line is deceptive, because the range of kills represented on the y-axis is small (ranging from 20 to 23 kills). The lower adjacent value represents a very large number of kills. Other than adding another visual aid in evaluating the kill distribution for Bull Breaching, this box plot does not offer any significant insight. In fact, the Bull Breaching analysis is quite straightforward due to the excessive kills realized by the LF. However, the analysis of this scenario is of great value when we begin to compare results between the three MCM methods employed.

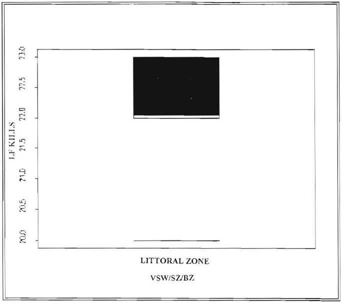

Figure 5. Box Plot of Total Landing Force Kills; Bull Breaching Scenario.

2. Traditional Scenario

a. MOE 1

Table 3 is identical to the Bull Breaching CPA table, except that the data pertains to CPA for the Traditional Scenario. On average, 10.2 landing force units per run made it ashore following the traditional "in stride" MCM breaching efforts.

COMBAT POWER ASHORE; TRADITIONAL SCENARIO												
RUN NUMBER	SCENARIO TIME (MINUTES)											TOTAL ASHORE
	110	115	120	125	130	135	140	145	150	155	160	
RUN 1	0	0	0	0	0	0	0	4	1	0	0	5
RUN 2	0	0	2	0	1	1	2	4	3	0	0	13
RUN 3	0	0	2	0	4	2	3	4	3	0	0	18
RUN 4	0	0	0	0	0	2	3	2	2	0	0	9
RUN 5	0	0	0	0	0	1	1	3	2	0	0	7
RUN 6	0	2	0	0	0	2	2	3	3	0	0	12
RUN 7	0	1	0	0	1	2	1	4	3	0	0	12
RUN 8	0	1	1	0	0	1	0	2	1	0	0	6
RUN 9	0	1	2	0	4	2	2	4	1	0	0	16
RUN 10	0	0	0	0	2	2	0	0	0	0	0	4
AVERAGE	0	0.5	0.7	0	1.2	1.5	1.4	3.0	1.9	0	0	10.2

Table 3. Combat Power Ashore as a Function of Time; Traditional Scenario.

b. MOE 2

Table 4 summarizes LF kill categories for the Traditional Scenario. Again, it is important to focus on SZ kills. The expectation is that of the three littoral zones being evaluated, the SZ would account for the majority of total LF kills. However, this was not the case with this scenario. Notice that under total kills, the average number of kills in the SZ was 6.1, while in the BZ it was 10.4. After further study, it became apparent that what is occurring is that the traditional MCM SZ/BZ assets (the AAVs) were breaching or partially breaching lanes in the SZ, but were not surviving long enough to make it to the beach.

LANDING FORCE KILLS; TRADITIONAL SCENARIO														
RUN NUMBER	TOTAL KILLS				AAV KILLS				LCAC KILLS				LCAC KILLS	LCAC KILLS
	VSW	SZ	BZ	TOTAL	VSW	SZ	BZ	TOTAL	VSW	SZ	BZ	TOTAL	INBOUND	OUTBOUND
RUN 1	0	8	14	22	0	7	6	13	0	1	8	9	5	4
RUN 2	0	5	9	14	0	3	6	9	0	2	3	5	1	4
RUN 3	0	3	8	11	0	3	2	5	0	0	6	6	0	6
RUN 4	0	7	11	18	0	6	5	11	0	1	6	7	3	4
RUN 5	0	6	15	21	0	4	8	12	0	2	7	9	4	5
RUN 6	0	9	7	16	0	8	1	9	0	1	6	7	2	5
RUN 7	0	5	13	18	0	4	5	9	0	1	8	9	2	7
RUN 8	0	10	8	18	0	8	2	10	0	2	6	8	7	1
RUN 9	0	2	6	8	0	1	3	4	0	1	3	4	3	1
RUN 10	0	6	13	19	0	4	5	9	0	2	8	10	10	0
AVERAGE	0	6.1	10.4	16.5	0	4.8	4.3	9.1	0	1.3	6.1	7.4	3.7	3.7

Table 4. Landing Force Kills; Traditional Scenario.

Recall from the Bull Breaching analysis that if MF breaching efforts were reasonably effective, one would expect about equal LCAC kills inbound as outbound, and in the Traditional Scenario this expectation is realized with 3.7 LCAC kills in both those categories.

Figure 6 is a multiple box plot of total LF kills and total SZ kills. It is not intended that a comparison be made between these two kill categories. This plot is useful in that it serves as a quick indicator of the prominent features of the data distributions. The total LF kills are obviously skewed toward lower values, with a median of 18 and a mean of 16.5. Also, that both of these kill categories contain lower adjacent values at the extremes indicates that if more scenario runs were conducted, one might expect the mean to fall even further. So, the possibility exists that the Traditional Scenario MCM assets are actually more effective than the data suggests.

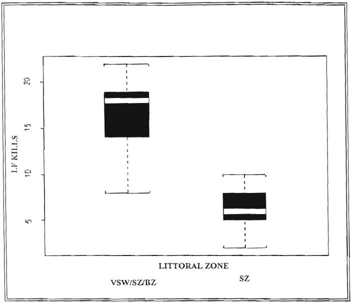

Figure 6. Multiple Box Plot of Total Landing Force Kills and Total SZ Kills; Traditional Scenario.

c. MOE 3

Table 5 summarizes MCM asset kills from the Traditional Scenario. As was expected, no VSW MCM assets (Mk 105) were killed. A telling result is the average number of AAVLC kills. One AAVLC per lane was killed during almost every run of the scenario. If the AAVLC was killed prior to the BCP, the point at which the line charge could be fired, then the line charge was not fired and no breaching was accomplished by that unit. If, however, the AAVLC was killed after the BCP, then the line charge was successfully employed prior to that unit's death. Given that the AAVPs were intended to proof the lanes breached by the AAVLCs, if the AAVLCs were killed prior to line charge employment, then the AAVPs would have lower probabilities of successfully breaching up to the landing site. This is the case because high BZ mine densities would remain and the plow has a relatively low probability of surviving if a mine detonates during plowing operations. It appears that the preceding assessment is exactly what is occurring, given an average of 4.8 SZ/BZ MCM asset kills.

MCM KILL; TRADITIONAL SCENARIO														
RUN NUMBER	VSW MCM KILLS MK105 A1	MK105 A2	MK105 B1	MK105 B2	TOTAL VSW KILLS	SZ/BZ MCM KILLS AAV A1(LC)	AAV A2	AAV A3	AAV B1(LC)	AAV B2	AAV B3	TOTAL SZ/BZ KILLS	TOTAL MCM KILLS
RUN 1	0	0	0	0	0	1	1	1	1	1	1	6	6
RUN 2	0	0	0	0	0	1	1	0	1	0	1	4	4
RUN 3	0	0	0	0	0	1	1	0	1	0	1	4	4
RUN 4	0	0	0	0	0	1	1	1	1	1	1	6	6
RUN 5	0	0	0	0	0	1	1	1	1	1	1	6	6
RUN 6	0	0	0	0	0	0	0	1	1	1	1	4	4
RUN 7	0	0	0	0	0	1	0	1	1	1	1	5	5
RUN 8	0	0	0	0	0	1	1	1	0	0	1	4	4
RUN 9	0	0	0	0	0	1	0	1	1	0	0	3	3
RUN 10	0	0	0	0	0	1	1	1	1	1	1	6	6
AVERAGE	0	0	0	0	0	0.9	0.7	0.8	0.9	0.6	0.9	4.8	4.8

Table 5. MCM Kills; Traditional Scenario.

Figure 7 offers an alternative for viewing the information contained in Table 5. Notice that the data is slightly skewed toward higher values.

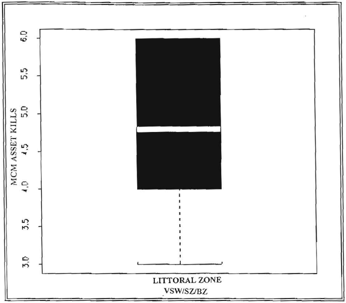

Figure 7. Box Plot of Total MCM Asset Kills.

Table 6 contains estimated percentages of breaching completed by SZ/BZ MCM assets. Breaching percentages were calculated using the known length of the lane section that each unit was assigned to breach and the known location of each unit's death. The difference between the kill point and the intended breaching completion point represents the uncleared portion of lane. Breaching completion percentages were estimated using that information. The aggregate average breaching completion was 53 percent. That means that on average, 47 percent of the intended breaching area in the SZ/BZ portion of the two lanes was not cleared.

ESTIMATED PERCENTAGE OF BREACHING COMPLETED BY MCM ASSET IN SZ/BZ; TRADITIONAL SCENARIO							
RUN NUMBER	AAV A1(LC)	AAV A2	AAV A3	AAV B1(LC)	AAV B2	AAV B3	EST. AVG. PER RUN
RUN 1	.33	1.0	.33	.25	.25	.25	.40
RUN 2	.66	.33	1.0	.5	1.0	.5	.67
RUN 3	.33	.33	1.0	.25	1.0	.5	.57
RUN 4	.66	.66	.33	.25	.25	.5	.44
RUN 5	.33	.33	.66	.25	.5	.5	.43
RUN 6	1.0	1.0	.33	.25	.25	.25	.51
RUN 7	.66	1.0	.33	.25	.25	.5	.50
RUN 8	.33	.33	.66	1.0	1.0	.25	.60
RUN 9	.66	1.0	.66	.5	1.0	1.0	.80
RUN 10	.33	.33	.33	.25	.5	.5	.37
AVERAGE	.53	.63	.56	.38	.60	.48	.53

Table 6. Estimated Percentage of Breaching Completed by Traditional Scenario SZ/BZ MCM Assets (AAVs) Prior to Asset Being Killed.

Finally, Figure 8 is a bar graph comparing the percentage of LF kills per run to percentage of SZ/BZ breaching completed per run. The best way to analyze this graph is to compare any two runs. In general, as breaching percentages increase from one run to another, the LF kill percentages will fall between those two runs. For instance, run 1 achieved approximately 40 percent breaching and realized nearly 100 percent LF kills, while run 2 achieved about 70 breaching and only 60 percent LF kills. Of the three runs which managed only 40 percent breaching or lower, all three experienced greater than 90 percent LF kills. We are led to the simple principle: *Heavy losses of MCM assets imply heavy losses in the LF.*

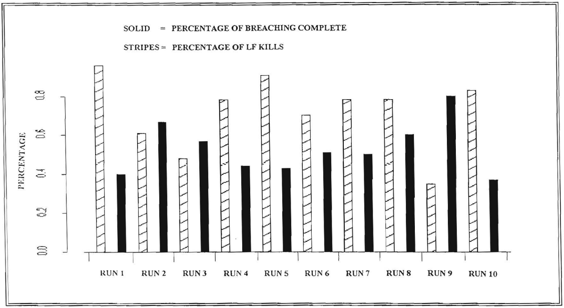

Figure 8. Bar Graph Comparing Percentage of Landing Force Kills Per Run To Percentage of SZ/BZ Breaching Complete Per Run for Traditional Scenario.

3. Lemmings Scenario

a. MOE 1

Table 7 represents CPA for the Lemmings Scenario. On average, 19.6 LF units made it ashore per run, or over 85 percent of the total force.

COMBAT POWER ASHORE; LEMMINGS SCENARIO												
RUN NUMBER	SCENARIO TIME (MINUTES) 110	115	120	125	130	135	140	145	150	155	160	TOTAL ASHORE
RUN 1	1	3	1	1	2	2	3	4	3	0	0	20
RUN 2	1	3	1	1	2	3	3	3	3	0	0	20
RUN 3	1	3	1	1	3	3	3	4	3	0	0	22
RUN 4	1	4	0	0	2	2	2	3	2	0	0	16
RUN 5	1	4	1	1	3	3	2	4	3	0	0	22
RUN 6	1	4	1	1	1	3	3	3	3	0	0	20
RUN 7	1	3	1	1	3	3	3	3	3	0	0	21
RUN 8	1	2	1	0	2	3	3	4	3	0	0	19
RUN 9	0	3	1	1	2	2	3	4	3	0	0	19
RUN 10	1	2	1	1	2	3	1	4	2	0	0	17
AVERAGE	0.9	3.1	0.9	0.8	2.2	2.7	2.6	3.6	2.8	0	0	19.6

Table 7. Combat Power Ashore as a Function of Time; Lemmings Scenario.

b. MOE 2

Table 8 contains LF kill categories specific to the Lemmings Scenario. For this scenario, the average total LF kills is 4.3 per run. Notice that the average number of BZ kills in all kill categories is close to zero, and that total SZ kills account for the majority of total kills (though it is only 2.1 SZ kills per run). As was the case with the Traditional Scenario, inbound and outbound LCAC kills are nearly equal.

LANDING FORCE KILLS; LEMMINGS SCENARIO														
RUN NUMBER	TOTAL KILLS				AAV KILLS				LCAC KILLS				LCAC KILLS	LCAC KILLS
	VSW	SZ	BZ	TOTAL	VSW	SZ	BZ	TOTAL	VSW	SZ	BZ	TOTAL	INBOUND	OUTBOUND
RUN 1	6	1	0	7	3	0	0	3	3	1	0	4	0	4
RUN 2	0	2	1	3	0	2	0	2	0	0	1	1	1	0
RUN 3	1	0	0	1	1	0	0	1	0	0	0	0	0	0
RUN 4	5	4	1	10	1	3	0	4	4	1	1	6	3	3
RUN 5	1	0	0	1	0	0	0	0	1	0	0	1	1	0
RUN 6	2	1	0	3	1	1	0	2	1	0	0	1	1	0
RUN 7	1	2	0	3	0	1	0	1	1	1	0	2	1	1
RUN 8	1	4	0	5	1	3	0	4	0	1	0	1	0	1
RUN 9	2	2	0	4	2	2	0	4	0	0	0	0	0	0
RUN 10	1	5	0	6	0	3	0	3	1	2	0	3	3	0
AVERAGE	2.0	2.1	0.2	4.3	0.9	1.5	0	2.4	1.1	0.6	0.2	1.9	1.0	0.9

Table 8. Landing Force Kills; Lemmings Scenario.

Figure 9 is a multiple box plot providing another way to view total LF kills and total SZ kills. In both cases, the data is skewed toward higher values. Notice that during one run, the upper adjacent value for total LF kills climbed as high as 10 and the lower adjacent value fell to one in another run.

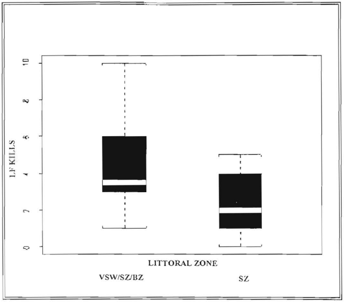

Figure 9. Multiple Box Plot of Total Landing Force Kills and Total SZ Kills; Lemmings Scenario.

c. MOE 4

MOE 4 is specific to this scenario. Table 9 summarizes MOE 4 and measures the number of mines neutralized by Lemmings. The number of Lemmings killed equals the number of mines neutralized. Recall that 80 mines per lane were expected based on worst case minefield densities, for a total of 160 mines between the two lanes. Utilizing 1.62 Lemmings per mine, the average number of mines neutralized was 135.4, or about 85 percent of the expected number.

LEMMINGS KILLED/MINES NEUTRALIZED			
RUN NUMBER	LEMMING SWARM A	LEMMING SWARM B	TOTAL LEMMING KILLS
RUN 1	70	84	154
RUN 2	67	55	122
RUN 3	81	70	151
RUN 4	77	66	143
RUN 5	85	62	147
RUN 6	80	47	127
RUN 7	64	61	125
RUN 8	58	55	113
RUN 9	63	70	133
RUN 10	86	53	139
AVERAGE	73.1	62.3	135.4

Table 9. Lemming/Mine Kills; Lemming Scenario.

Figure 10 is a box plot of total mine kills data from Table 9. The box plot appears to represent a normal distribution. Note here that with Lemmings we have a different principle: *Heavy losses of Lemmings MCM assets implies increased survivability of the LF.*

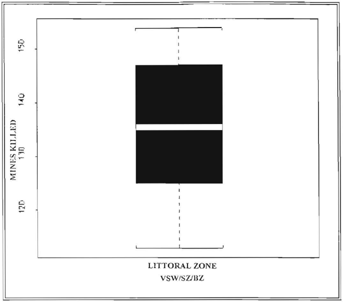

Figure 10. Box Plot of Total Lemming/Mine Kills; Lemming Scenario.

B. COMPARATIVE ANALYSIS

1. MOE 1

The graph in Figure 11 compares average CPA versus time between the three scenarios. The differences in CPA are obvious, with Bull Breaching realizing the least number of forces ashore and Lemmings realizing the greatest number. The last of the AAVs reaches the landing site around the 140 minute mark and the first LCAC reaches the beach around the 144 minute mark. Given this information, the Bull Breaching CPA curve is horizontal from about the 118 mark until the 132 mark, indicating that over a 14 minute period no forces (AAVs in this case) reached the beach. Similar lulls in CPA occur in the other scenarios around this same time frame, though not for as long. As it turns out, this time interval coincides with the time that the first AAVs are crossing through the SZ. The "gap" is the only zone which produces such distinct horizontal stretches in the CPA curves of all three scenarios.

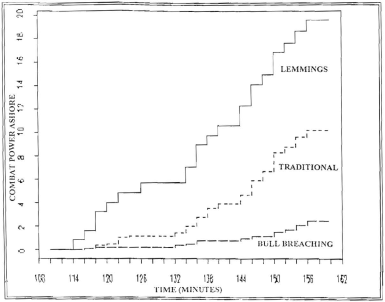

Figure 11. Comparing Average Combat Power Ashore Between Scenarios.

2. MOE 2

Table 10 compares total LF kills between the scenarios. It is obvious that total LF kills fall dramatically between scenarios, with Bull Breaching having the most and Lemmings the least number of average kills. Notice that in all littoral zone categories, similar drops between scenarios occur, except for BZ kills between Bull and Traditional. As discussed in the Traditional Scenario analysis section, the reason for no decline in BZ kills between these two scenarios is that the SZ/BZ MCM assets in the Traditional Scenarios are being killed before they can reach the BZ. The reason these MCM assets are dying prior to the BZ is the "gap". The SZ region is the most difficult for traditional MCM assets to effectively handle.

TOTAL LANDING FORCE KILL COMPARISON BETWEEN SCENARIOS

RUN NUMBER	BULL BREACHING TOTAL KILLS				TRADITIONAL SCENARIO TOTAL KILLS				LEMMING SCENARIO TOTAL KILLS			
	VSW	SZ	BZ	TOTAL	VSW	SZ	BZ	TOTAL	VSW	SZ	BZ	TOTAL
RUN 1	6	7	10	23	0	8	14	22	6	1	0	7
RUN 2	2	6	14	22	0	5	9	14	0	2	1	3
RUN 3	5	12	5	22	0	3	8	11	1	0	0	1
RUN 4	5	9	8	22	0	7	11	18	5	4	1	10
RUN 5	8	7	8	23	0	6	15	21	1	0	0	1
RUN 6	3	10	9	22	0	9	7	16	2	1	0	3
RUN 7	5	4	14	23	0	5	13	18	1	2	0	3
RUN 8	3	5	12	20	0	10	8	18	1	4	0	5
RUN 9	3	7	12	22	0	2	6	8	2	2	0	4
RUN 10	5	6	12	23	0	6	13	19	1	5	0	6
AVERAGE	4.5	7.3	10.4	22.2	0	6.1	10.4	16.5	2.0	2.1	0.2	4.3

Table 10. Total Landing Force Kill Comparison Between Scenarios.

Figures 12 and 13 are multiple box plots comparing total LF kills and total SZ LF kills between scenarios, respectfully. They clearly show the drop in LF kills experienced as a result of different MCM methods employed. The difficulty in effectively countering the SZ mine threat with traditional MCM methods is illustrated once again by the similarities between the box plots of total SZ LF kills (Figure 11) for Bull Breaching and Traditional. Appendix F contains additional box plots of the different LF kill categories.

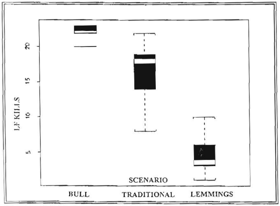

Figure 12. Total Landing Force Kills.

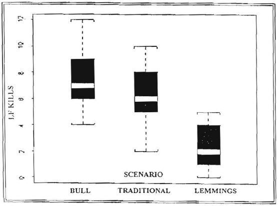

Figure 13. SZ Landing Force Kills.

3. Mann-Whitney U Test

To determine whether the differences in MCM methods between scenarios are significant, the Mann-Whitney U test (one-tailed) is conducted on the following three pairs of breaching methods: Bull Breaching/Traditional (A1), Bull Breaching/Lemmings (A2), and Traditional/Lemmings (A3). The null hypothesis is identical for the three tests:

> H_O: The population relative frequency distributions for the effectiveness of the MCM methods are identical (i.e., there is no difference in the effectiveness of the different MCM methods).

The effectiveness of the different MCM methods is measured as a function of LF kills per scenario. The null hypothesis is tested against the following alternative hypotheses for each scenario pairing:

> H_{A1}: The population relative frequency distribution of Traditional Breaching effectiveness has shifted to the right of the relative frequency distribution for the population of Bull Breaching effectiveness (i.e., Traditional Breaching is more effective than Bull Breaching).
>
> H_{A2}: Lemmings is more effective than Bull Breaching.
>
> H_{A3}: Lemmings is more effective than Traditional Breaching

Using a significance level of 0.05 (alpha value), the following p-values were calculated from the Mann-Whitney U test (one-tailed):

* Bull/Traditional: p-value = 0.0005
* Bull/Lemmings: p-value = 0.0002
* Lemmings/Traditional: p-value = 0.0002

The null hypothesis is rejected in all three cases. Therefore, the Mann-Whitney U test suggests the following: that there is a high probability that the breaching method of the Traditional Scenario is more effective than that of the Bull Breaching Scenario; that Lemmings is more effective than Bull Breaching; and that Lemmings is more effective than Traditional Breaching. Based on the previous analysis, these results are not unexpected,

however, the Mann-Whitney U test offers further proof that the conclusions arrived at about the MCM simulation models are valid. Refer to Ref. 14 for details of how the p-values were obtained from the Mann-Whitney U test.

IV. CONCLUSION

A. SUMMARY

The objective of this thesis was to evaluate the effectiveness of the Lemmings swarming approach to "in stride" MCM in the VSW/SZ/BZ, and compare this new technology with current naval "in stride" MCM capabilities for those littoral zones. The objective was met by utilizing Janus to create three simulation models (scenarios) with which to test and evaluate the different MCM technologies and methods. The scenarios developed were executed 10 times each, with data being generated on each run. An analysis of the data was then performed, resulting in numerous tables and graphs summarizing the data relevant to the thesis objective. The analysis indicated clear and distinct differences among the various MCM methods modeled and tested.

During scenario development, it became necessary to limit the scope of the research, and as such, certain assumptions were made pertaining to the different MCM methods and scenario formulation. Recall that all three scenarios are identical except for the MCM methods employed. The assumptions made are summarized below.

The basic scenario, of which all three test scenarios are based, includes the amphibious landing, landing zone, and minefields. The assumptions made concerning this basic scenario are as follows:

* The LF is a single BLT, one-third of a typical AE, and is composed of 13 AAVs and 10 LCACs.

* The amphibious landing is an OTH operation, which leads to the assumption that the AAV is capable of an OTH landing.

* The landing is conducted unopposed by enemy fire, thus no NGFS is utilized, despite a guiding principle that you cover your open movements with fire. The reason for this assumption is that this thesis is analyzing MCM asset effectiveness, not the impact of enemy fire on the LF.

* The LCACs make only one round trip between the ATF and the landing site.

* The minefield densities are considered worst case.

* Mine types are assumed to include anti-tank mines in the BZ, bottom contact mines in the SZ, and magnetic influence mines in the VSW.

* The landing zone includes two landing lanes.

* Any breaching employed will be conducted under the auspices of "in stride" breaching.

The only assumption made concerning the Bull Breaching Scenario was that the amphibious landing be conducted without any breaching assets being employed. The landing force will bull its way through the minefield.

The assumptions made concerning the Traditional Scenario are as follows:

* Current Navy MCM assets were utilized to conduct "in stride" breaching.

* The Mk 105 mine sweeping hydrofoil was used to counter the magnetic mine threat.

* AAVs equipped with a line charge system were used to breach the BZ.

* AAVs equipped with mine clearing plows were used to proof the lanes cleared by the line charges and to further widen the lanes in the BZ.

* The MOP was not utilized to sweep the SZ due to its tendency to lose its magnetic charge, particularly in rough surf.

The assumptions made concerning the Lemmings scenario:

* Utilize Lemming swarms as the sole MCM asset for "in stride" breaching.

* A 1.62 Lemming-to-mine ratio is needed to achieve 95 percent clearance in a given sized landing lane.

* Lemming swarms are deployed by SEAL teams.

Along with the assumptions necessary to effectively simulate a real-world situation, certain expectations were formed prior to conducting any analysis of the

simulation output data. It was expected that Bull Breaching would result in the highest percentages of LF kills during an assault. Traditional Breaching assets were expected to outperform Bull Breaching. Additionally, the SZ region was expected to account for the majority of LF kills when utilizing traditional MCM methods. Because of the high density of the MF, kills in the Bull Breaching Scenario were expected to be proportional to the mine densities in the various littoral zones. The Lemming swarms were expected to effectively neutralize mines in the SZ. These pre-expectations served as a base with which to compare actual scenario data analysis.

The extensive data generated by Janus and packaged in the form of the Janus Post Processor provided the information with which all data analysis was performed. In general, the pre-expectations were realized. However, there were some exceptions, such as the high number of traditional MCM assets killed prior to reaching the BZ and the tremendous success of traditional MCM assets in the VSW. The analysis did support the Mine Warfare Plan's assessment of the dangers posed by the SZ to our current forces.

B. RECOMMENDATIONS

The evaluation of Lemmings as an effective "in stride" MCM for the VSW/SZ/BZ indicates that the system, as modeled, has real potential to significantly contribute to our MCM forces and to strengthen our ability to conduct effective, rapid, amphibious assaults in the world's littoral regions.

The objective of this thesis was not to highlight weaknesses in our current MCM forces, but rather was intended to produce relative performance evaluations of the MCM forces modeled in a very specific scenario with clear assumptions. The analysis suggests that traditional breaching methods would be effective in a real-world situation, with all assumptions (restrictions) removed. However, given the inherent danger and risk involved in an amphibious landing, high numbers of casualties could be expected when utilizing today's MCM assets. Lemmings analysis indicates that the Lemmings method could be substantially more effective than current MCM assets when conducting an "in stride"

breaching operation. Recall the negative impact that the "gap" had on the Traditional MCM assets, and how that impact resulted in heavy BZ LF losses. Lemmings offers a possible solution to the "gap" killing zone.

This thesis suggests that the Lemmings MCM system deserves serious attention and should be studied much more thoroughly, conducting real-world testing and analysis on the system. Simulation modeling does not completely represent the real-world, and that is not its intent. What simulation modeling can do is point out potential strengths and weaknesses of a given system. Then, based on an analysis of such models, decisions can be made about whether or not further research is in order for such a system. This thesis asserts that further research should be conducted on Lemmings and that real-world testing and analysis is called for with the Lemmings MCM system.

Today's MCM forces would be much more effective if supplemented by Lemmings. In a real-world situation, the combination of current MCM assets and Lemmings assets could make effective, reliable "in stride" breaching a reality.

APPENDIX A. LEMMINGS

The Lemmings swarming vehicle, designed and developed by Foster-Miller, Inc., offers one solution to the MCM problems associated with the VSW/SZ/BZ. Design specifications and operating parameters and characteristics were provided by Foster-Miller and are contained in this appendix.

Lemmings are currently undergoing field testing and analysis and are designed specifically to counter mines in the VSW/SZ/BZ utilizing a swarming approach to mine countermeasures. The initial development concentrated on several operational requirements needed to create such a swarming MCM system: the environment in which Lemmings would have to operate, the types of mines requiring neutralization, the method of neutralization, the sensors necessary to find such mines, the system platform (vehicle specifications), the best search pattern, and finally cost. The environment, the VSW/SZ/BZ, was generally considered to be uniform and benign, except for crashing waves. The uniform environment assumption was based on the probability that an enemy would only mine beaches and littoral regions susceptible to invasion, and hence would most likely be composed of sandy, muddy, and gravelly beaches, containing eel grasses and kelp, but no insurmountable natural obstacles (an invasion would not take place along a jagged, rocky coast).

The mines in such an environment were assumed to be counter-invasion mines (bottom contact, anti-tank, anti-personal, influence, etc.). However, anything manmade which is discovered in the invasion environment must be considered a target, since it could be an anti-invasion obstacle. Of course, manmade includes beer cans, fisherman's boots, and other trash, but such objects are dealt with either by number of MCM assets deployed or sensor capabilities of the Lemming.

The sensors chosen for Lemmings would need to detect both buried and exposed targets with a high degree of accuracy. The search pattern would need to offer the highest

probability of detection and the vehicle itself would need to be as robust and versatile as possible. Cost was always considered during the design phase of Lemmings. The swarming concept requires large numbers of vehicles to effectively counter mines, so cost was a big consideration during design. The results of Lemming R&D are summarized below by design and operational parameters.

Lemming are:

* Small, bottom crawling, expendable mine hunter-killers;
* Designed for massively parallel operations in the VSW/SZ/BZ;
* Adaptable to various delivery means (air, surface, or subsurface);
* Capable of flexible payloads (ordnance, surveillance, sensors, etc.).

Lemming capabilities are summarized:

* Each travels 3.8 miles, one acre swept path;
* Highly redundant search pattern;
* Detects buried or exposed targets;
* Command detonates and neutralizes target;
* Alternate missions include surveillance, reconnaissance, and marking.

Lemming features are summarized:

* Inexpensive (approx. $300 per vehicle);
* Small (0.8 cf/unit);
* Highly redundant;
* Lethal payload (7.5 lb);
* Covert;
* Clears tactical lane in 2 hrs;
* 98 percent mine clearance, 95 percent confidence;
* Simultaneous neutralization;
* Self sterilizes.

Lemmings benefits are summarized:

* Minimal platform exposure/personnel independent;
* Affordable training, operation;
* Minimal well deck volume;
* Operates in VSW/SZ/BZ;
* Platform independent;
* Frees lead landing craft for war fighting;
* Complements existing MCM.

Lemming swarms are capable of employing many different search patterns. Three of the most utilized are referred to as "Gaussian", "Face Mecca", and "Squeegee". The search patterns of individual Lemmings are referred to as quasi-random and combine to make the swarm patterns. First, what is meant by quasi-random?

Quasi-random refers to each vehicle's ability to be programmed to move forward a randomized amount of time limited to within x to y seconds, and then turn a randomized number of degrees, limited within certain levels. The values of the limits set the expansion rate of the swarm diffusion. If the time limit is kept short (e.g., 0 to 15 seconds), the straight travel legs are short and an intense search in a small area results, but the expansion is slow. Considerations involved are vehicle speed and search requirements. Foster-Miller has experienced the best results using 0 to 15 second time limits and 0 to 360 degree turn angles.

To "Face Mecca", each Lemmings is given a compass bearing (toward the beach), and every so many steps (e.g., 75 steps) the Lemmings face the beach (Mecca). They do not necessarily go toward the beach, rather they simply face it. This indexing biases the search pattern and the group migrates toward the beach. By altering the various parameters, the lateral dispersion can be influenced and the ability to "go back" and find missed mines can be achieved. "Face Mecca" swarms have been highly successful during simulation and field tests.

"Squeegee" is a pattern which means that at some interval, say 75 steps, the

vehicles move toward something, such as shallower water or the beach, rather than simply face it. The result is that each vehicle reaches the beach faster and in a denser swarm, however, if in their advance they happen to miss a mine, the algorithm will not allow them to go back. The "Squeegee" pattern is ideal for moving a swarm into a general area, but inadequate for searching.

Finally, the "Gaussian" pattern is when a swarm is deployed in the middle of a MF without any programmed headings. The pattern is simply Gaussian, and is ruled by the laws of statistics. Ideally, the "Gaussian" swarm is an extremely powerful tool and testing and analysis continue to look for the best way to employ this ability.

The best swarm for a given MF is usually a combination of the search patterns. For example, "Squeegee" might be utilized to get the swarm to move from shallower water to the VSW region (e.g., if Lemmings were deployed from a submarine which did not want to get to close). Once in the VSW, the swarm would employ "Face Mecca" to search for mines. For small MFs, the vehicles get short randomizations, and for large MFs, they get longer intervals, etc.

Foster-Miller has found that a 1.62 Lemmings-to-mine ratio is required to achieve 98 percent clearance of a given density MF. If that ratio is increased, the ability of Lemming swarms to cover such things as sensor failures and quicker coverage rates increases, as well.

APPENDIX B. MODELING SYSTEM PROBABILITIES

This appendix contains information on the percentage of reliability and survivability of each breaching asset, on landing force mine activation and kill probabilities, and on the dud probabilities of each mine type.

Each breaching asset is assigned a probability (reliability) that it will successfully neutralize each mine type it encounters, and a probability (survivability) that if it encounters a given mine type that it will survive that encounter. Reliability (R) and survivability (S) probabilities are contained in Table B1.

BREACHING ASSET RELIABILITY/SURVIVABILITY PROBABILITIES			
BREACHING ASSET	MAGNETIC INFLUENCE (R/S)	BOTTOM CONTACT (R/S)	ANTI-TANK (R/S)
Mk 105	95/90		
AAV LC		75/*	80/*
AAV P		75/75	90/75

Table B1. Reliability/Survivability Probabilities for Traditional Breaching Assets. The Star (*) Represents the Fact That Once a Line Charge is Expended, It Cannot Be Reused. Probabilities Expressed as Percentages.

Each landing force system (e.g., AAV, LCAC) is assigned a probability (activation) that it will activate a given mine type if such a mine is encountered, and a probability (kill) that if activation occurs will that unit be killed. Activation (A) and kill (K) probabilities for landing force systems are contained in Table B2.

MINE ACTIVATION AND KILL PROBABILITIES			
LANDING FORCE SYSTEM	MAGNETIC INFLUENCE (A/K)	BOTTOM CONTACT (A/K)	ANTI-TANK (A/K)
AAV	85/75	80/75*	90/85*
LCAC	75/30	10/40	20/50

Table B2. Probabilities of Mine Activation and Probabilities of Being Killed If Activated For Landing Force Systems. The Star (*) Indicates Percentage Based On Track Hitting the Mine. Probabilities Expressed as Percentages.

Finally, Table B3 contains the probability that each mine type will fail to activate if encountered by a breaching asset or landing force system (dud probability).

MINE TYPE	MINE DUD PROBABILIY
Magnetic Influence	4
Bottom Contact	4
Anti-Tank	3

Table B3. Mine Dud Probabilities Expressed as Percentages.

APPENDIX C. SCENARIO IMAGES

Selected images copied from actual runs of the Janus scenarios are contained in this appendix. The figures are arranged in chronological order, with general setup images presented first, followed by Bull Breaching images, Traditional images, and finally Lemmings images. A brief explanation of each image is included below.

General scenario images:

Figure C1. Full View of the Landing Zone and Littoral Regions. The Coast Appears as a Brown Line.

Figure C2. Red Force Helicopter Laying Magnetic Mines in the VSW.

Bull Breaching Scenario:

Figure C3. The AAV Approach Formation At About 15 nm Off-Shore with Movement Routes Shown.

Figure C4. The AAVs Moving into Column Formation to Cross Through the MF and the LCAC Wave Approaching At About 15 nm.

Figure C5. LCACs Crossing MF Following the Loss of 13 of 13 AAVs.

Figure C6. The "Lone" LCAC" After the Loss of 9 of 10 LCACs.

Traditional Scenario:

Figure C7. AAVs Commencing Their Assault Through Breached Landing Lanes. Breached Areas Are Indicated By Yellow Lanes.

Figure C8. LCACs Crossing MF Following the Loss of 3 of 13 AAVs.

Figure C9. 2 of 10 LCACs Were Killed Crossing the MF.

Lemmings Scenario:

Figure C10. Movement Routes of ZODIACs to the Lemmings Drop Point At the Mouth of Each Landing Lane.

Figure C11. Lemmings Just After Deployment. Each Lemming Symbol Represents 43 Individual Lemmings, Thus Making Up Two Swarms of 129 Lemmings Each.

Figure C12. 28 Lemmings Were Killed, Which Indicates that 28 Mines Were Neutralized.

Figure C13. Zero AAVs Were Killed.

Figure C14. Zero LCACs Were Killed.

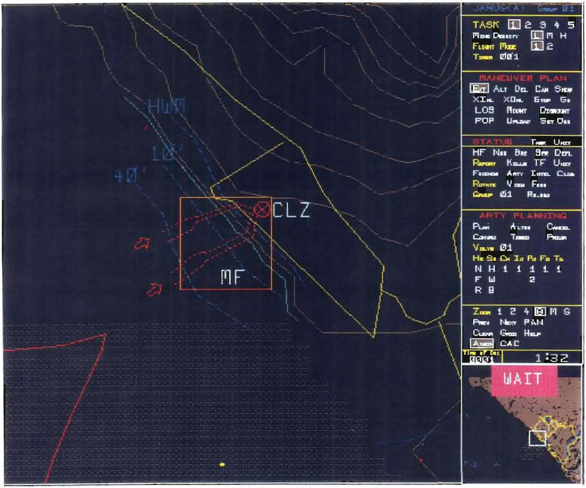

Figure C1. Full View of the Landing Zone and Littoral Regions. The Coast Appears as a Brown Line.

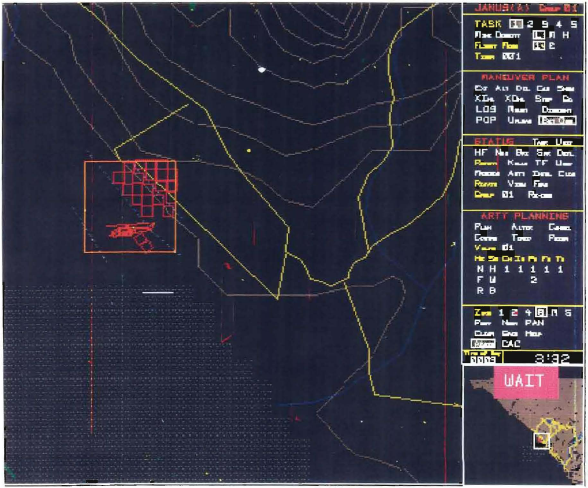

Figure C2. Red Force Helicopter Laying Magnetic Mines in the VSW.

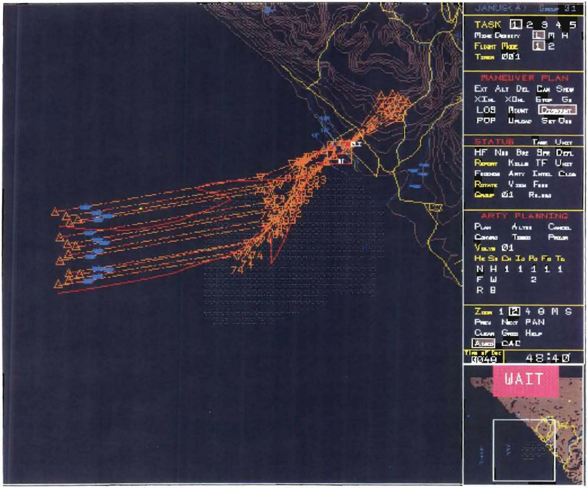

Figure C3. The AAV Approach Formation At About 15 nm Off-Shore with Movement Routes Shown.

Figure C4. The AAVs Moving into Column Formation to Cross Through the MF and the LCAC Wave Approaching At About 15 nm.

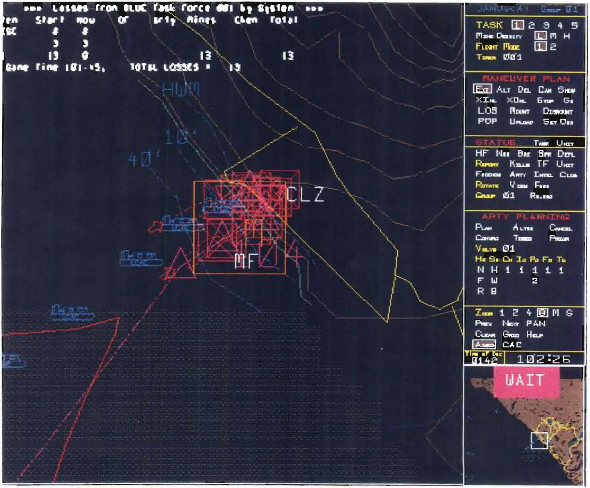

Figure C5. LCACs Crossing MF Following the Loss of 13 of 13 AAVs.

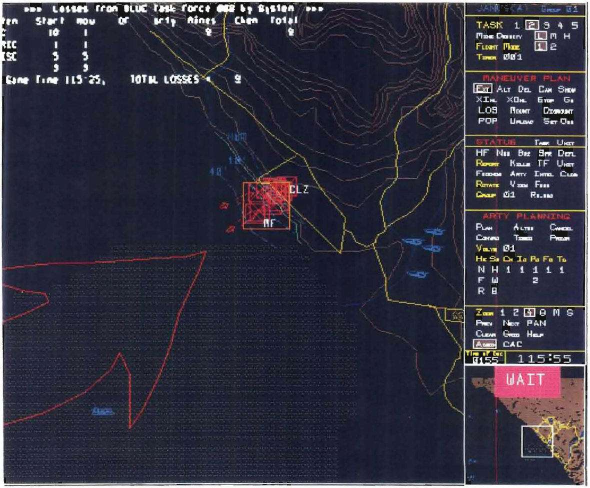

Figure C6. The "Lone" LCAC" After the Loss of 9 of 10 LCACs.

Figure C7. AAVs Commencing Their Assault Through Breached Landing Lanes. Breached Areas Are Indicated By Yellow Lanes.

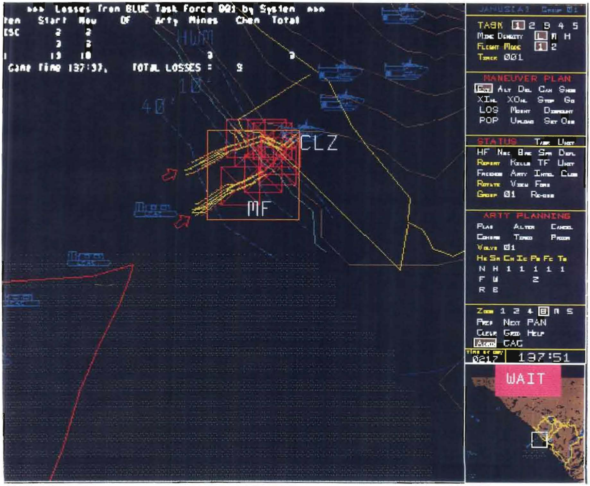

Figure C8. LCACs Crossing MF Following the Loss of 3 of 13 AAVs.

Figure C9. 2 of 10 LCACs Were Killed Crossing the MF.

Figure C10. Movement Routes of ZODIACs to the Lemmings Drop Point At the Mouth of Each Landing Lane.

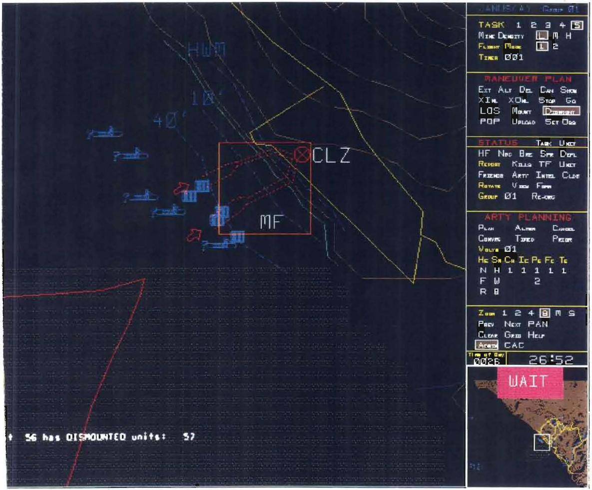

Figure C11. Lemmings Just After Deployment. Each Lemming Symbol Represents 43 Individual Lemmings, Thus Making Up Two Swarms of 129 Lemmings Each.

Figure C12. 28 Lemmings Were Killed, Which Indicates that 28 Mines Were Neutralized.

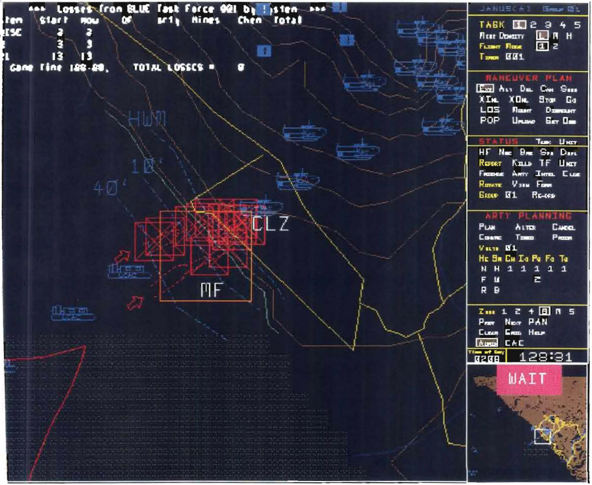

Figure C13. Zero AAVs Were Killed.

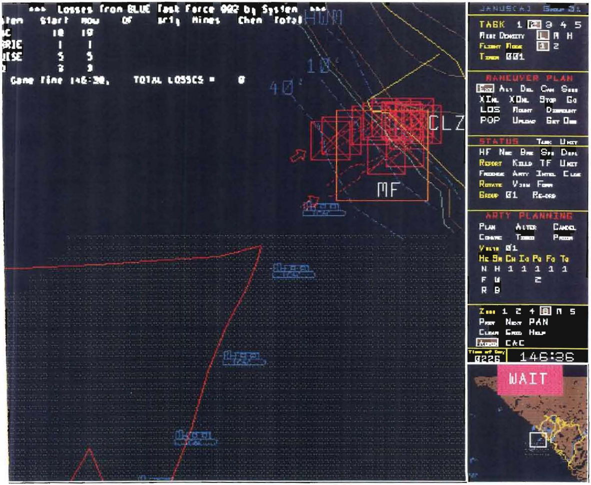

Figure C14. Zero LCACs Were Killed.

APPENDIX D. DESCRIPTIVE STATISTICS

General descriptive statistics on the various LF kill categories are included in this appendix and are summarized in Table D1.

TOTAL LF KILLS				SZ LF KILLS			
	Bull	Traditional	Lemmings		Bull	Traditional	Lemmings
Mean	22.2	16.5	4.3	Mean	7.3	6.1	2.1
Median	22.0	18.0	3.5	Median	7.0	6.0	2.0
Variance	0.84	19.17	7.79	Variance	5.79	6.32	2.99
TOTAL AAV KILLS				**SZ AAV KILLS**			
	Bull	Traditional	Lemmings		Bull	Traditional	Lemmings
Mean	12.2	9.1	2.4	Mean	5.2	4.8	1.5
Median	12.0	9.0	2.5	Median	4.5	4.0	1.5
Variance	0.84	7.88	2.04	Variance	2.84	5.51	1.61
TOTAL LCAC KILLS				**SZ LCAC KILLS**			
	Bull	Traditional	Lemmings		Bull	Traditional	Lemmings
Mean	10.0	7.4	1.9	Mean	2.1	1.3	0.6
Median	10.0	7.5	1.0	Median	2.0	1.0	0.5
Variance		3.82	3.66	Variance	1.43	0.46	0.49
TOTAL LEMMING/MINE KILLS				**TOTAL MCM ASSET KILLS**			
	Lemmings Scenario				Traditional Scenario		
Mean	135.4			Mean	4.8		
Median	136.0			Median	4.5		
Variance	166.04			Variance	1.16		

Table D1. Descriptive Statistics on LF Kill Categories.

APPENDIX E. LF KILL CATEGORY BOX PLOTS

Additional box plots of the various LF kill categories are contained in this appendix.

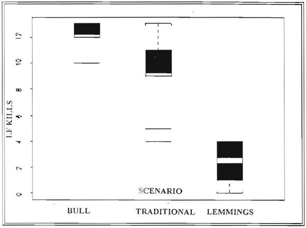

Figure E1. Total AAV Kills.

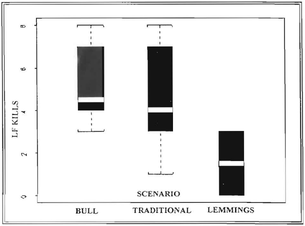

Figure E2. SZ AAV Kills.

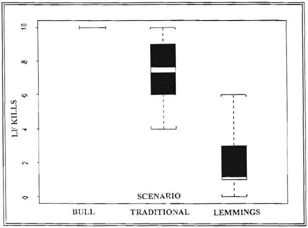

Figure E3. Total LCAC Kills.

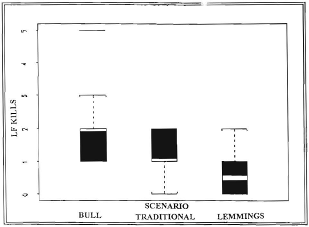

Figure E4. Multiple Box Plot of SZ LCAC Kills.

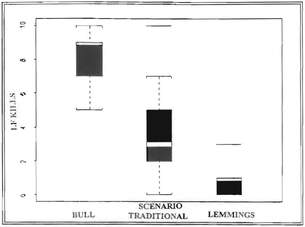

Figure E5. Multiple Box Plot of Inbound LCAC Kills.

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Monterey, California 93943-5000

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Department of Mathematics
Naval Postgraduate School
Monterey, California 93943-5000

11. Bard Mansager 2
Code MA/Ma
Adjunct Professor of Mathematics
Naval Postgraduate School
Monterey, California 93943-5000

12. Carlos F. Borges 2
Code MA/Bc
Assistant Professor of Mathematics
Naval Postgraduate School
Monterey, California 93943-5000

13. CDR Richard Brown 2
Code NS/Br
NSA Dept.
Naval Postgraduate School
Monterey, California 93943-5000

14. Capt Wayne Hughes 1
Code OR/Hl
Senior Lecturer
Naval Postgraduate School
Monterey, California 93943-5000

15. Capt Thomas Hoivik 1
Code SM/Ho
Senior Lecturer
Naval Postgraduate School
Monterey, California 93943-5000

16. Lt. Timothy R. Weber 2
219 Avery St.
Decatur, Georgia 30030

17. Dr. William H. Weber III 2
219 Avery St.
Decatur, Georgia 30030

18. Rita M. Weber 2
346 Davis St.
Portsmouth, RI 02871